Keywords:
Pumped storage
Pumped-storage experience
Operations and maintenance

EPRI GS-7325
Project 1745-15
Final Report
May 1991

Operation and Maintenance Experiences of Pumped-Storage Plants

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REPORT SUMMARY

Operation and Maintenance Experiences of Pumped-Storage Plants

Owners, operators, and designers of hydroelectric pumped-storage plants now have access to the combined operation and maintenance (O&M) knowledge of more than 30 operating plants around the world. The lessons learned should maximize the benefits of solutions developed for typical operational problems.

INTEREST CATEGORY

Hydroelectric

KEYWORDS

Pumped storage
Pumped-storage experience
Operations and maintenance

BACKGROUND As time passes and experienced staff retire, many pumped-hydro O&M lessons learned are forever lost. To ameliorate the situation, EPRI has documented good O&M practices and problem solutions from both domestic and foreign projects. This report provides a comprehensive record of proven effective practices that minimize forced outages and shorten scheduled repairs.

OBJECTIVES To record the accumulated civil, geotechnical, mechanical, and electrical O&M knowledge and experiences of 35 domestic and foreign pumped-storage plants.

APPROACH For each pumped-storage project, the basic data were compiled from available information and sent to each plant for verification. If needed, a subsequent visit was made by the investigating team, comprised of electrical, mechanical, civil, and geotechnical engineers.

The plant visits usually took a full day and included a roundtable discussion that covered operations, maintenance scheduling and outages, turbine and generator experiences, ancillary equipment problems, civil and hydraulic problems, and ideas for future improvement. The discussion was followed by a visit to accessible parts of the project, and questions and answers were exchanged on the basis of what had been viewed. Where plants were undergoing major overhaul, site-visit reports on inspection of the damage and the resultant repair were written and submitted to the plant superintendent for verification before final reporting.

RESULTS The main operating problems tended to occur in connection with the turbine and the main circuit breakers. In general, the civil works and generator/motor problems do not cause forced outages and could be dealt with by careful, planned maintenance.

The cavitation damage on solid stainless steel runners was less than with stainless steel overlay on mild steel; the same was true for wicket gates.

Unit circuit breakers were a continuing maintenance problem at most plants. The best circuit breakers (SF_6 or vacuum) have a rated life of two to three years in a pumped-storage plant. These breakers are rated at 2000 to 3000 close-open operations, which is a factor of about 10 above older designs.

Where significant vibration was present, attention was directed at minimizing the driving force and increasing the ability of the turbine/generator and enclosing structure to dampen or absorb vibration. The many mode changes on pumped-hydro units require a significant portion of the operating time to be spent in rough zones, thus putting a great emphasis on vibration damping. Split runners were a definite problem but were made better by welding the cover plants in place.

Trashrack problems are not uncommon at new pumped-storage plants. Vibration-related failures of either the upstream or downstream trashracks have occurred and are resolved by either bracing or redesign.

EPRI PERSPECTIVE Pumped-storage plants are extremely rugged, and when good experiences from other plants are incorporated, high reliability can be achieved. Trouble-free operation requires that the designers and operators do not repeat past mistakes. When the lessons learned from good experiences are incorporated, a highly reliable and valuable storage plant is added to the utility system to complement its baseloaded units.

PROJECT

RP1745-15

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ABSTRACT

This report presents the results of a study on Operation and Maintenance (O&M) practices in hydroelectric pumped storage plants. The objective of this project, which was sponsored by EPRI, is to record the practical knowledge on the O&M of a number of the domestic and foreign pumped storage plants which has been accumulated by their operating staff.

Civil, geotechnical, mechanical and electrical aspects of O&M of the thirty-five plants visited are discussed, and some general conclusions, as warranted by the commonality of the problems, are drawn. These conclusions may be useful to the planners and designers of future pumped storage projects.

In general, due to their layout, diversity and different modes of operation, the plants have few common problems which, in most cases, are limited to the mechanical and electrical aspects of the plants' operation.

The data on plants' specifications, operation and maintenance were collected during field trips in 1985, 1986 and 1988. Only the visited plants are discussed in this report.

ACKNOWLEDGEMENTS

This research project was sponsored by the EPRI's Generation and Storage Division. The encouragement and guidance provided by Mr. Antonio Ferreira, Project Coordinator, and Mr. C. W. Sullivan, Program Manager, were essential to the successful completion of this project and accordingly are greatly appreciated.

The authors also wish to acknowledge the assistance provided by Mr. A. G. Strassburger and Mr. M. S. Vasilescu of the Review Board for their review and comments on this document.

Additionally, the authors express their appreciation for the time and effort expended by the many plant operators and operating personnel. We offer a special thanks for the help provided by Mr. T. Kidahashi of Electric Power Development Co., Ltd. for arranging plant visits in Japan and by Professor Stojan Sedmark, University of Belgrade and Professor G. M. Karadi, University of Wisconsin, Milwaukee, for arranging the visit to Bajina Basta in Yugoslavia.

CONTENTS

SUMMARY

GENERAL

The purpose of the study presented herein was to present information pertaining to the operation and maintenance of hydroelectric pumped storage plants to the hydro industry for use in their planning, design, operation and maintenance practice.

This information is presented in a report which summarizes the O&M experience gained by the operators at over thirty plants, both domestic and overseas, in the course of their daily operation.

Some recommendations are also suggested to the planners and designers of future pumped storage plants. The report is concluded with the description of the O&M experience as reported by the plants' operators and utilities representatives.

More detailed information such as the plant data, field trip reports etc., organized in seven appendices, appear at the end of the report.

Field inspections, which were the principal means of collecting the O&M experience data, were the most interesting and educational part of the study. The investigators were impressed with the ingenuity and resourcefulness demonstrated by the operators of many plants in solving various unforseen operational problems.

The plant factors (generation) for domestic and European plants are similar, with the average being 0.128. The equivalent factor for pumping is 0.179. Japanese plants appear to operate at lower factors. The two plants for which data is available have average generation and pumping factors of 0.044 and 0.052 respectively.

Interestingly enough, the overseas and particularly European operators use their machines as synchronous condensers to a much greater degree than their U.S. counterparts.

MAINTENANCE

The longevity normally associated with hydroelectric power plants, many of which work for 50 years or more, is not as pronounced in the case of the hydroelectric pumped storage plants. Frequent operational mode changes cause heavy wear and tear on the mechanical and electrical equipment which, coupled with the more pronounced vibration during pumping, result in a significant increase in maintenance.

Total operation and maintenance costs for pump storage plants vary from 1.01 to 37 mils per kWh, with an average of 6.36 mils per kWh. Most plants schedule unit inspection on an annual basis, with overhaul every ten years. An annual inspection requires 800 to 1200 manhours, and an overhaul about 15,000 manhours.

PROBLEMS

The problems encountered were assigned to 31 categories. Of the 83 mechanical problems reported, 15 concerned wicket gates, 11 concerned wearing rings and 10 each concerned runners and shut-off valves. Wicket gate problems included bearings, seals, cavitation and corrosion. Two wicket gate cascade failures were reported. Some wearing rings fell off and flange covers came loose from split runners for various reasons. Shut-off valve problems were mainly wiped seals. The problems of runner cavitation on the pumped storage plants are not significantly different from those prevailing at conventional hydro plants. However, wicket gate cavitation damage is more pronounced. Runners either constructed in, or overlayed with, stainless steel and stainless steel wicket gates show, as expected, a much lower incidence of cavitation than those made of carbon steel. Of the 68 electrical problems the most often reported were: premature wear on circuit breakers, (19 reported) coil wedge looseness (18 reported) corona damage and transformer problems (each with seven reported). There were only nine civil/geological problems reported, six of which were leakage from the upper reservoir.

RECOMMENDATIONS

Some plant design features which are considered advantageous are adequate space for maintenance and transformer replacement, facilities for operators (as remote operation has not proven practical), stainless runners and wicket gates, and long life circuit breakers.

All data were checked and in most cases reviewed by the respective plant operators. The authors would, however, appreciate it if any errors and omissions were brought to their attention for correction.

Section 1

INTRODUCTION

BACKGROUND

Several scenarios of the future development of the electrical generation industry of the U.S. have been developed. It is, however, clear that the difficulties of bringing new nuclear and fossil-fuel plants on line (for technical, environmental or financial reasons) will eventually be only partially offset by conservation by industry and public users. Future growth of the economy, and load growth, may dictate an increasingly flexible use of U.S. generation resources. Flexibility in a system is considerably enhanced by the presence of hydropower capacity which has the unique capability to pick up load quickly and economically. Most of the conventional large capacity, economically attractive hydro sites have already been developed and severe restrictions can be expected in attempts to develop the few remaining sites. It is likely, therefore, that future development of major hydro resources will center on the provision of new pumped storage or the conversion of existing schemes. In addition to the quick and flexible response, pumped storage plants are able to inexpensively store generated base energy for use in peaking, a feature which in itself adds to the operational flexibility of the system.

There are more than 24 pumped storage plants in the U.S. with an installed capacity above 200 MW and many more in other developed countries. For most of the disciplines involved in the planning and design, the technology used in the design and construction would not be considered state-of-the-art. However, most of the plants are used arduously, some of them to a greater degree than was envisaged at the design phase. The frequent mode changes, together with the conditions during pumping, which are often less than ideal, lead to maintenance in excess of that expected or experienced in a normal hydro plant. Information related to actual operating experience is generally held by a limited number of organizations, usually the owner, and databases, such as that operated by the Edison Electrical Institute. The operating experience is considered to be of vital importance to utilities considering future pumped storage construction and to designers attempting to plan an economical and efficient facility. The size of most plants, and the time taken for planning, licensing, designing, construction and commissioning of a plant, make it

unlikely that any utility manager or individual engineer will take a significant position in the design or management of more than one pumped storage plant in his professional life. It was therefore considered useful to gather together highlights of the operating and maintenance experience of plants to serve as an additional reference for operation and maintenance of existing pumped storage facilities and for planners and designers of future facilities.

OBJECTIVES AND SCOPE

The objective and scope of this study was to obtain practical knowledge from operating and maintenance personnel on their experiences at existing operating commercial pumped storage plants, and to present this knowledge, and all plant data, in a form which will alert potential developers and engineers to some of the considerations which should be addressed in the planning and design of new facilities and the scheduling and maintenance of existing and new plants.

The scope of this study was limited in two ways:

- With few exceptions, plants covered by this study were equipped with reversible Francis pump/turbines, and total plant capacity was in excess of 200 MW (excepting Horse Mesa and Mormon Flat, which are smaller). The study was also limited to those plants with significant operational experience. These restrictions eliminated plants such as Flat Iron and Clarence Canyon from the study, although historically they could supply interesting and valuable lessons in power development.

- The study was limited to U.S. plants except for a few foreign installations which demonstrated very heavy or unusual use, or which included machines or concepts which might be applicable to U.S. practice in the foreseeable future. One notable plant which was not included in the study was La Rance, which is based on low head pump/turbines using seawater as a medium. Although North American, British and Japanese utilities are all considering both tidal power plants and pumped storage schemes using seawater, it is such an exceptional operating condition that it was felt that La Rance should remain outside the scope of this report.

The best way of achieving this goal was to visit each plant to discuss the conditions directly with the operating and maintenance staff in order to gain the information that is difficult to transmit by written communications.

An analysis of pumped storage plants was prepared and then a choice to be made of the power projects worthy of investigation. The chosen subjects of the study within the U.S. were:

- Bath County, VA - 2592 MW, 6 units.
- Bear Swamp, MA - 600 MW, 2 units, underground plant.
- Blenheim Gilboa, NY - 1000 MW, 4 units.
- Cabin Creek, CO - 300 MW, 2 units.
- Carters, GA - 750 MW, 2 pump/turbines; 250 MW, 2 turbines.
- Castaic, CA - 1275 MW, 6 units.
- Fairfield, SC - 511 MW, 8 units.
- Helms, CA - 1053 MW, 3 units, underground plant.
- Horse Mesa, AZ - 366 MW, 1 pump/turbine; 93 MW, 3 turbines.
- Jocassee, SC - 612 MW, 4 units.
- Lewiston, NY - 240 MW total, 12 units.
- Ludington, MI - 1658 MW, 6 units.
- Mormon Flat, AZ - 86 MW, 1 pump/turbine; 44 MW, 1 turbine.
- Mt. Elbert, CO - 200 MW, 2 units.
- Muddy Run, PA - 800 MW, 8 units.
- Northfield Mountain, MA - 846 MW, 4 units, underground plant.
- Raccoon Mountain, TN - 1530 MW, 4 units, underground plant.
- Salina, OK - 260 MW, 6 units.
- San Luis, CA - 388 MW, 8 two-speed units.
- Seneca (Kinzua), PA - 422 MW, 2 pump/turbines; 26 MW, 1 turbine.
- Smith Mountain, VA - 547 MW, 3 pump/turbines; 150 MW, 2 turbines.
- Taum Sauk, MO - 408 MW, 2 units.
- Wallace, GA - 321 MW, 4 pump/turbines; 56 MW, 2 turbines.
- Yards Creek, NJ - 330 MW, 3 units.

Subjects of study outside the U.S. and their reason for inclusion were:

- Dinorwig, U.K. - 1550 MW, 6 Units - Britain's newest plant, probably operated the most rigorously of any existing plant.
- Ffestiniog, U.K. - 360 MW, 4 Units with separate turbines and pumps - This plant has been used consistently in excess of its design criteria and this led to more stringent design criteria for Dinorwig.

- Turlough Hill, Ireland - 290 MW, 4 Units - The only pumped storage plant on the isolated Irish system, and therefore operated rigorously. Also includes an unusual rock excavation.

- Le Truel, France - 40 MW, 1 Unit - The only two-stage reversible units in operation with both stages regulated.

- Montezic, France - 912 MW, 4 Units - France's latest plant and one of the largest in the world with runner removal from below.

- Bajina Basta, Yugoslavia - 348 MW, 2 Units - Currently highest head Francis unit in the world with any operating history.

- Minghu, Taiwan - 1000 MW, 4 Units - Taiwan's only pumped storage scheme.

- Numappara, Japan - 675 MW, 3 Units - Until recently, this was the highest head reversible Francis units in the world and it has a reasonable operating history.

- Shintoyne, Japan - 1125 MW, 5 Units - Fairly high head plant with split runner.

- Masegawa, Japan - 288 MW, 2 Units - This plant includes large Deriaz units.

- Okuyahagi, Japan - 2 Plants - 343 MW, 3 Units and 783 MW, 3 Units - The only high-head pumped storage plant in the world with three reservoirs and two powerhouses.

METHODS OF INVESTIGATION

For each project, the basic data was compiled from available information and sent to each plant for verification. Later, a visit was made by the investigating team, comprising electrical, mechanical and civil engineers, and sometimes accompanied by a geotechnical engineer and/or an EPRI representative.

Visits normally took a full day and were scheduled to include a round-table discussion, which covered Operation; Maintenance Scheduling and Outages; Turbine Experience; Generator Experience; Ancilliary Equipment Problems; Civil and Hydraulic Problems; and Ideas for Future Improvement. The discussion was followed by a visit to parts of the project which were accessible, followed by questions and answers based on what had been viewed. In a number of cases, the operators were kind enough to start the units (in the pumping or generating mode, as convenient). Some plants were undergoing major overhaul during the visit, which allowed inspection of damage and repair.

Reports on the site visits were written and submitted to the plant superintendent for verification before publication. These reports form the main bulk of this report, but they have been summarized in the following sections.

The investigators wish to express their thanks for the help and understanding rendered them by the management and operating staff of the inspected plants, and all of those who contributed to this report. Discussion of various plants' deficiencies is not intended to reflect on the performance of the plant operators or anyone else, but rather to provide a body of experience for the future pump storage plant planners and designers, and as a reference for operating and maintenance personnel who must deal with problems on a daily basis with resourcefulness to achieve the generally high availability of these projects.

CONCLUSIONS

In general, pump storage plants studied were operating with excellent records of availability and had overcome the normal setbacks during construction. The investigators were unable to discover any outstanding modifications that would enable existing or new plants to increase efficiency or economy drastically. However, some problems do continue to plague the operation of pumped storage and might usefully be tackled by future development. Among the common problems are:

- Wedge failures.
- Balancing line failures.
- Wearing ring failures.
- Shutoff valve seal failures.
- Trashrack failures.
- Damaging vibration.
- Power circuit breaker problems.

These and other less common problems have been highlighted in the text and developers should ensure that they are satisfied with a designer's attempts to minimize or mitigate the effects of these problems.

Section 2

RECOMMENDATIONS

GENERAL

The diverse nature of the problems described precludes the itemizing of major conclusions. However, any would-be developer of pumped storage should consider the following items in planning the project. All the items mentioned will have a benefit to the plant, but may not be demonstrably economical.

DETAILED RECOMMENDATIONS

Adequate Space

Designers sometimes have a tendency to underestimate the space required around major equipment. The provision of adequate laydown areas throughout pumped storage plants is of paramount importance. If the site is such that an on-site maintenance shop can be built, there is less necessity for laydown areas within the plant because many items of ancillary equipment can be transported to the maintenance building intact. However, dismantling of the generator/motor, pony motor (if provided), turbine, shutoff valve and operator, governor, major control boards, low voltage bus, etc. will invariably be done within the powerhouse. Dismantling of each of these items often requires substantial outside cleaning, special tools, work on two or more levels of the powerhouse, cleaning of individual parts, marking and labeling, and accurate measurement. Designers should play their part in ensuring that the operations can be logically, quickly and safely performed, minimizing the handling of parts and allowing for sandblasting and other cleaning methods. Powerhouses containing three or less units tend to be cramped during maintenance and special care is needed.

Finally, a subjective assessment of space required should be made by operating staff, based on their own experience and on examination of existing plants.

Intermediate Shaft

The use of a removable intermediate shaft should be considered, together with a turbine hall. Although such an arrangement clearly increases the powerhouse height (and cost), it greatly eases the access to the head cover and turbine and results

in easier handling of all the parts in the turbine pit, particularly when undertaking tasks requiring removal of the head cover. Both plants that included this feature had made arrangements to limit the noise from the turbine by muffling and shielding the area.

Runner Materials

Runners should be of stainless steel. The superior corrosion and cavitation resistance is proven and consideration should also be given to the provision of stainless steel wicket gates and other turbine parts such as the upper draft tube.

Balancing Lines

Balancing lines should be corrosion resistant or protected and should be designed to avoid cavitation. In addition, as far as possible, flexible connections should be used where they connect to the turbine.

Spare Parts

Developers should give consideration to the need for drawings of the parts of crucial ancillary equipment. Current indications are that the breakers will require constant refurbishment and that spares will, after a few years, have to be made to order. Developers should ensure that the contractual arrangements at time of construction allow for the provision of detailed drawings of all parts of these type of items. It is suggested that language be included in the contract to require submission of such drawings at the time of construction.

Unit Breakers

Unit breaker specifications should call for a minimum maintenance interval of at least 3000 close-open operations and a total unit life of at least 40,000 close-open operations. These being a major maintenance item, designs should be sympathetic to access requirements and substitution of spare breakers.

Turbine Shutoff Valve

Turbine shutoff valve seals should operate on penstock pressure and should be fail-safe. Interlocks should be provided to prevent movement of the rotating element when the seals are closed and inadvertent opening of the seals.

Penstock Intake Gates

The history of penstock examinations, and silt inflow on extreme drawdown, indicates that arrangements should be made to allow isolation of the penstock(s) from

the upper reservoir. The cheapest way to do this is by a simple stoplog, with a bypass arrangement to fill the penstock.

Plant Personnel Facilities

Experience indicates that pumped storage plants should all be considered as manned stations, even if only for the normal working week, rather than around the clock. Therefore, developers are advised to include facilities for operation and maintenance personnel. The crew size varies, but sufficient facilities for regular operation and maintenance personnel should be included, together with facilities for storage of tools and equipment.

Vibration

Developers should be cognizant of the substantial vibration occurring in reversible Francis units during low flow and the damage that can result from that vibration. Design should take this into account and it is recommended that design be on the conservative side.

Transformers

This investigation indicates that a surprising number of transformers have experienced problems and that ease of removal and replacement should be an important consideration. It should be noted that later transformers have been troubled less than those for earlier schemes, so designs may well be more robust.

Plant Model

At least one plant advised that a physical model or a high quality CADS model be made of a bay of the proposed plant during design, and selection of equipment. This practice of model-making has long been accepted in process engineering, nuclear and thermal, and may also have useful benefits in pumped storage design.

Trashracks

Trashracks tend to suffer damage and should be designed to avoid vibration and cracking von Karman vortices. The same spacing should be used top and bottom.

Drains

Drains throughout power plants should always be oversized and easy to clean to avoid clogging during construction and operation. Care should be taken to ensure that drains are sized to cope with expected inflow from equipment in the area of

each drain. Particular care should be taken with head cover drains, which seem to be of insufficient capacity in many cases.

Bearings

Bearings should have babbit cast to the shell after it is tinned rather than having it sprayed on. Extreme care should be employed in aligning the shaft to avoid bearing failures.

Air Storage Tanks

Air storage tanks should be sized conservatively to provide blowdown air for the maximum practicable starting sequence. The system should avoid high pressures because of the shock that occurs with quick opening valves.

Capital vs. Operating Costs

Before the final layout of the plant in a pumped storage scheme, the designers should determine the cost of maintenance staff, past history of downtime on large units, the amount of downtime that can be accommodated in the plant operation, and outline studies should be made on the logistics of machine maintenance. Clearly at the design stage time and motion studies cannot be made of every maintenance operation, but designers and planners should endeavor to work with machinery manufacturers to ensure that they have an understanding of the cost (in maintenance terms) of any restriction of space. Designers should take into account in this analysis the incremental differences in powerhouse construction costs rather than relying on simple determination of unit rates.

Section 3

REPORTED EXPERIENCE

GENERAL

At most plants visited, the Plant Manager (or deputy) and the maintenance superintendents were available for discussion. The information sought was gladly given and notes taken by interviewers. The field visit reports based on those notes are the basis of this report and form Appendix B.

In general, the plant managers indicated that the plant performance was satisfactory and the versatility of pumped storage had been demonstrated again and again. However, it was also indicated that having discovered the versatility of pumped storage, dispatchers tended to rely heavily on their characteristics in the electrical system operation. Such reliance emphasizes the requirement for minimum planned and forced outage, and reinforced the necessity of easy maintenance and quick repair.

The main operating problems tended to occur in connection with the turbine, ancillary equipment, and the main circuit breakers. It appeared that, in general, civil works and generator/motor problems did not usually cause forced outages and could be dealt with by careful, planned maintenance.

With a few notable exceptions, the major problems occurring at each plant were diverse and it is not possible to conclude that pumped storage projects are liable to a particular kind of failure. The range of problems have, however, been summarized below.

REVIEW OF DESIGN PHILOSOPHIES

General

Some parts and systems used in pumped storage have been the subject of design focus during the development of the major equipment, either because the use of such equipment is arduous or because it is not present in conventional hydro stations. The parts and systems in question, including starting methods, turbine and wicket

gate materials, and wicket gate restraints and bearings, have been itemized below with a short note on each about the current design philosophies being adopted.

Turbine Materials

The plants included in this report are almost equally divided between units with stainless steel runners and those with mild steel runners with stainless steel overlay. As expected, the latter have required more cavitation repair with the area of overlay often being extended during each repair. In these cases, a common comment was a desire to have all stainless runners. In the case of Yards Creek, Cabin Creek and Lewiston, the original mild steel runners were replaced by stainless steel runners, although the prime reason for changing runners was mechanical failure, not the cavitation performance.

The trend is toward a greater use of stainless, particularly 13-4 (ASTM A743 Gr CA-6NM) with its greater resistance to corrosion and cavitation damage, along with good weldability.

Cavitation damage also often occurs on the wicket gates, which are normally fabricated of mild steel. Four of the plants visited, Yards Creek, Turlough Hill, Cabin Creek and Northfield, have stainless wicket gates. At Yards Creek, the original mild steel gates were changed to stainless steel at the same time as the runner change described above. The carbon steel wicket gates were also changed for stainless steel ones at Northfield and on one unit at Cabin Creek. Most of the foreign plants visited have stainless steel runners and wicket gates.

Wicket Gate Restraint

The method of protecting the gate mechanism for pump turbines follows the general philosophy of conventional hydraulic turbines. About 65% of the plants inspected utilized only a breaking element (usually a shear pin). About 27% utilized a breaking element together with a friction restraining device, and 8% used only a friction device. A few plants experienced a significant amount of shear pin breakage, and both Smith Mountain and Salina experienced progressive shear pin failures. Although these did not have catastrophic results, friction devices were added at both plants to avoid future problems.

Wicket Gate Bearings

Most of the plants visited utilized grease lubricated wicket gate bearings. There is a generally accepted belief that teflon bearings will not withstand the pounding occurring in a pump turbine. The wicket gate bearings on one unit at Blenheim-

Gilboa were changed to a self-lubricating (Lubrite) type, but there is insufficient operating time to assess their performance. The EPDC plants in Japan (Numappara and Shintoyne) also have self-lubricating wicket gate bearings which operated with no apparent problems.

The only reported problem was with the seals, which sometimes failed, and several plants have replaced the original seals with quad ring or chevron type seals, which have given no reported failures.

Distributor Seals

All of the plants visited, except for Montezic and Le Truel, were equipped with seals to reduce leakage at the top and bottom of the wicket gates. These are normally confined by the facing plates, but in the case of Turlough Hill, where the seals were added after commissioning, they are installed in the wicket gates themselves. The majority of the seals are rubber or neoprene with a few brass or bronze and two nylon. In both Blenheim-Gilboa and Castaic, the original elastomeric seals were changed to have bronze contact surfaces.

Turbine Shutoff Valves

Of the plants visited, 60% had spherical turbine inlet valves, 8% had butterfly valves, and 32% had no valve. The rated turbine net heads for spherical valves was between 646 and 1568 feet and for butterfly valves between 197 and 529 feet. Of the twelve plants without inlet valves, eight have individual penstocks and four have bifurcated penstocks.

With the exception of Ffestiniog and Taum Sauk, all spherical valves are equipped with upstream and downstream seals. The majority of these seals are water-operated, and Taum Sauk was changed from oil to water. The valves at Ffestiniog are so-called "straightflow" type, in which rather than a spherical plug, the closing member resembles an eyelid.

All the inlet valves, both spherical and butterfly, are both opened and closed by a hydraulic operator, usually using oil, with the exception of Dinorwig, which is closed by a weighted lever.

Starting Methods

Almost every possible starting method for units in the pumping mode has been used in at least one plant. Three of the newer large U.S. plants use static electronic equipment to convert 60 Hz power to variable frequency AC power for synchronous

starting. They have been trouble-free to date, except that at Mount Elbert, extensive design changes, and about 150 field changes, were required to commission the system following installation. The newer overseas plants also use static AC frequency converters with great success (Dinorwig, Montezic and Minghu, for example).

Pony motors, reduced-voltage and full-voltage across-the-line starting have each been used in several plants, with the choices being determined by the capabilities and limitations of the electrical transmission systems.

Synchronous or semi-synchronous, back-to-back starting has also been used at several plants. This method uses one unit as a generator/motor or a separate generator/motor to start a second unit as a pump. The two are synchronized together on a separate bus, either at zero speed for a synchronous start, or at a low speed for a semi-synchronous start. The two are then brought up to rated speed, synchronized to the electrical system and the generating unit is dropped off. This method works well when there is sufficient water in the upper reservoir. However, the last unit cannot be started as a pump with this method. The usual practice is to have one or two units equipped with an alternate method of starting, either pony motor or reduced-voltage starter.

OPERATION OF PUMPED STORAGE PLANTS

The pumped storage plants in the U.S. which formed the basis for this study varied in their usage, but a typical pattern could be discerned. Over 80% of the U.S. plants are, or have recently been, operating on a weekly cycle, meeting daily loads and pumping nights and weekends.

As discussed in other literature, the benefits of the pumped storage plants to a power system are manifold, but at present the preferred use of the plants appears to be confined to dependable peaking capacity, economic energy storage, occasional speed regulation (load following), maintaining load at off-peak, and power factor correction.

Typical U.S. Plant Cycle

Most plants pump from about 11:00 p.m. through 6:00 a.m., usually with as many units as can be put on line. The pumping cycle is typically followed by generation starting about 7:00 or 7:30 a.m. Depending on the geographic location and characteristics of the electrical power system or power pool which operates the plant, generation will often continue throughout the day but usually there are morning and

afternoon peaks. A minority of plants, most notably Bath County, reported semi-regular daytime pumping and some plants even report three discrete generation peaks a day. Such use leads to an average of six to eight mode changes per day, but a more realistic overall average is six (three start-stop cycles). Pumping is usually performed on weekends, which imposes a weekly cycle on the daily cycle. The average daily elevation of the water in the upper reservoir drops during the week and pumping throughout the weekend raises the level to absolute maximum by about 6:00 a.m. on Monday morning. The use of existing plants is increasing with notable exceptions at Smith Mountain, Yards Creek and Taum Sauk, all of which have seen a decrease in usage.

Twenty-five percent of the U.S. plants visited use their units to participate in the control of system frequency when generating while the others are block-loaded, usually from a remote dispatching operation.

The time of generation, taken as a percentage of the total for all units possible, varied between 0.5 percent for Taum Sauk and 37.7 percent for Jocassee, the average being 13.8 percent. The plant factor, the energy generated as a percentage of the maximum at rated output, is generally close to the percent of time operating, the average being 11 percent. This indicates that the average load is 80 percent of the rated load. It might be expected that plants with conventional units, i.e., significant streamflows into the upper reservoir, would show generation times above average, but this is not the case. In fact, with the exception of Seneca, the plants with conventional units operate less than the average. In the case of Seneca, which generates 22.1 percent of the time, the pump/turbines generate 19.6 percent of the time, so the conventional unit is not solely responsible for the high usage. The percentage of pumping time varied between 1.4 percent for Taum Sauk and 34.2 percent for Jocassee, the average being 16.4 percent. The pumping factor, the energy used as percentage of the maximum rated input, also averages 16.4 percent. As to be expected, the average pumping load is very near the rated conditions.

The use of pumped storage units as synchronous condensers appears to have little value in U.S. systems. Castaic recorded such use for about 7 hours per day and Cabin Creek for about four hours. Blenheim-Gilboa has been called upon to operate in this mode about 10 hours per month. Nevertheless, most plants are able to operate as a synchronous condenser in at least one direction, which may well be useful in unusual circumstances. It was noted, for instance, that Ludington had operated as a synchronous condenser during national holidays when maintenance was being carried out on transmission lines or other modifications resulting in voltage-raising

were being made to the system. In the case of Cabin Creek, even though the turbine was disconnected for more than 12 months, a unit was able to function as a synchronous condenser during that time.

Other U.S. Plant Cycles

Two plants, Lewiston and San Luis, have operating regimes philosophically very different from normal. Their design (and operating regime) is based more on the concept of water storage rather than the system requirements for energy storage. Lewiston's purpose is to store water for subsequent release into the headworks of the Robert Moses plant at Niagara Falls. The treaty regulating use of Niagara River water allows greater withdrawals at night and Lewiston takes advantage of that provison to supplement the available daytime water for the Robert Moses power plant.

San Luis forms a key storage facility in the California Central Valley Project and is intended to store seasonal surplus water from the Sacramento-San Joaquin Delta, primarily for summer irrigation use within the San Joaquin Valley. It was constructed to include pumping/generating capacity to act as an energy as well as water storage. Since it was designed and is operated as bulk seasonal water storage, it was decided to install units without wicket gates but with two-speed generator/motors.

Operational Regimes of Foreign Projects

Many of the pumped storage plants visited overseas were operating in the same manner as U.S. plants and were being used for peak loading. However, some occupied a special place in their respective distribution systems, as described below.

Minghu, Taiwan. Minghu is the only pumped storage scheme in Taiwan. The power system has a total installed capacity of 13.21 GW, of which hydro accounts for 13.1%, thermal 55.2%, and nuclear power 31.7%. In terms of energy output, nuclear plants have been responsible for 61.0% of output and hydro 18.0%. Minghu has been built to act in a peaking role in conjunction with the base load nuclear power generation. The plant has been used to follow load and has operated as a synchronous condenser fairly regularly. It usually operates on a daily cycle with two generating peaks and is in operation regularly for 22 hours per day.

Dinorwig. The British generation system, comprising the North of Scotland Hydro Board and the Central Electricity Generating Board (CEGB), operates almost independently of the rest of Europe, although there is one intertie across the Channel.

Dinorwig, part of CEGB, was designed to operate in conjunction with the proposed CEGB 1320 MW thermal units and to provide rapid response system reserve of up to 1300 MW in 10 seconds. The system requirement for frequency control dictated a criterion of more than 40 mode changes per day. However, by the time construction was completed, the system characteristics had changed to such an extent that Dinorwig is of greater benefit operating as a spinning reserve or for peaking. It is also economical to operate the plant as a replacement for other older, less efficient plants for normal generation and to use the plant to absorb system output during pumping. Although the revised regime places less emphasis on frequency regulation, nevertheless 40 mode changes per day on a unit is typical. (This equates to 12 mode changes involving breaker operation.)

Ffestiniog. Ffestiniog, now supplemented by Dinorwig, was the first pumped storage scheme on the CEGB system. Since its original commissioning, its use increased dramatically for frequency control and peaking. Its sustained use for these purposes, with daily mode changes in excess of 30, were a leading reason to design Dinorwig to be so flexible.

Turlough Hill. Turlough Hill is the only pumped storage scheme on the Eire system and comprises a significant part of the installed capacity. The system is isolated and Turlough Hill is providing an extremely fast response to load change to maintain system frequency and stability. At least two machines (capacity 146 MW total) are operated at a minimum load of 5 MW, to be able to pick up load within one second. This is not a very efficient way to operate, but provides a quicker response than moving from motoring in air to generating (which can be done between 3 and 55 seconds).

MAINTENANCE SCHEDULING

The maintenance requirements of pumped storage schemes are significantly less than for comparable sized thermal plants. However, the intensity of use and the variety of functions that pumped storage plants are required to perform result in preventative and remedial maintenance above that which is experienced in conventional hydropower plants.

The amount of work scheduled for maintenance at each plant depends on the age of the plant, the complexity of design, the required operation, the history of forced outages (or for newer plants, the starting up experience), the time since the last major overhaul, and the standard procedures and scheduling of the owner's operating

departments. The rigorous "standardized" approach was more evident in the overseas projects visited than in U.S. plants.

Throughout the U.S., the maintenance philosophy for the mechanical and electrical components tended to be the same. In general, at discrete intervals, usually 1 year, preventative maintenance was carried out on each unit. This usually consisted of cavitation damage inspection and repair, inspection of bearings, bearing clearances, valves, generator/motor windings and wedges, ancillary turbine and generator/motor systems, and cleaning of brushes, coolers, filters, etc. The preventative maintenance also usually includes adjustment of clearances and repair of other plant equipment, such as circuit breakers, transformers, penstocks and tunnels, gates, valves, etc.

Cabin Creek has adopted a policy of two inspections per year. During the first short inspection period, repair work is limited, but lists of required work and spares are prepared for a second maintenance period scheduled later in the year.

Some of the plants containing smaller units, such as Salina, Muddy Run and Lewiston, have increased the time between maintenance somewhat but also include in the scheduled preventative maintenance period rotor removal to ensure full checking of wedges and windings, as well as cavitation repair of the turbine.

Apart from those plants mentioned above, the maximum time between preventative maintenance outages was reported by San Luis and Raccoon Mountain, which both recorded intervals of two years. In the case of San Luis, the plant is operated on a seasonal cycle and therefore is not subject to intense cyclic usage. In the case of Raccoon Mountain, it was reported that due to the continuing problems in commissioning of the units, the plant has not entered a regular cycle of preventative maintenance, but the proposal was to embark on a two-year interval based on circuit breaker maintenance timing.

OPERATION AND MAINTENANCE COSTS

All U.S. plants were invited to offer budgetary estimates of operation and maintenance costs, and other information was derived from the DOE publication, "Historical Plant Cost and Annual Production Expenses for Selected Electric Plants." Extreme costs were excluded from the information available and the rest of the costs were brought to 1987 dollars and averaged. These calculations indicate that a total operating and maintenance budget, excluding cost of electricity for pumping, varies between 1.01 and 37 mils/kWh, and the average figure is 6.36 mils/kWh.

Plants undergoing substantial maintenance, such as a unit overhaul, record both a high actual operating and maintenance cost and a low usage. Under these conditions, an O&M cost above 10 mils/kWh could be expected.

Not enough information was available to determine trends of costs over time for a particular plant, and it should be noted that costs often included supplementary costs associated with maintenance of smaller plants included in the same organizational unit as the pumped storage plants.

Man-hours required for annual unit maintenance for U.S. plants also varied, usually between 800 and 1200 man-hours per year per unit. In contrast, some operators of larger units (above 200 MW) with substantial operation were allocating up to 4000 man-hours per unit per annum for regular maintenance.

Man-hours required for overhaul varied from 6700 man-hours for small units to 36,000 man-hours for larger units. For estimating purposes, developers and planners should allow at least 15,000 man-hours for a 10-year overhaul.

Major Equipment Overhaul

Many of the U.S. plants visited had not yet performed a major equipment overhaul. However, of those plants reporting major overhaul, the interval for doing such work varied widely, between 5 years (for Smith Mountain) and 16 years (for Muddy Run). For planning, however, based on the reported experience, 10 years would appear to be the "average" time between major overhauls.

Work carried out during a major overhaul usually included: removal of rotor, pony motor (if applicable), bearings, head cover, runner, wicket gates, etc., cavitation repair on runners and wicket gates, wicket gate seal repair, draft tube refurbishment, bearing replacement, generator/motor rewedging, and general cleaning and adjustment. As with other aspects of the maintenance, the time taken for this work varied from two and a half months (6000 man-hours) at the small Lewiston units to nine months (projected) for the very large Ludington units. Generally, for the purposes of planning, five months (21 weeks) could be considered to be the average time for a major overhaul. Overhaul scheduling is significantly influenced by the following:

- In-house or contractor labor.
- Time of the year during which work is done.
- Laydown areas available.

- Cranes available.
- Size of the unit.

With respect to the planning of the major overhaul, in most cases the decision to dismantle a unit was made because of an increasing incidence of forced outages or an awareness of conditions that might lead to serious forced outage. Almost invariably, the condition of the turbine rather than the generator/motor dictated the major overhaul. Some of the power plants engaged the original turbine manufacturer to inspect the machines, and their report usually led to the decision to dismantle the unit.

Few plants in the U.S. showed evidence of a plant-based systematic measuring of plant parameters in order to help plan future maintenance, although Yards Creek was able to demonstrate a gradual rise in pumping/generating ratios until a major overhaul, with a consequent improvement in the ratio. At Lewiston and Blenheim-Gilboa, partial discharge analyses are used to monitor the stations.

Maintenance scheduling was handled somewhat differently abroad. The most sophisticated overall policy was being pursued by Electricite de France (EDF). The company is in the midst of a program which is attempting to statistically predict the appropriate time to replace a component or a system. Predictions are being made based on a record of performance of parts or systems. For instance, graphs can be drawn of downtime against age for a system. During commissioning and early life, downtime will be high as the "bugs" are worked out; then, during a substantial part of the system life, downtime will be low; finally, as parts wear, clearances increase, materials deteriorate, etc., the system will exhibit ever increasing downtime until major refurbishment or replacement is required. The EDF program is attempting to derive wear curves for significant parts or systems in hydro plants so that major repair or replacement can be scheduled at the optimum time (i.e., just before downtime starts increasing).

In Britain, a less rigorous approach was taken, but in both stations visited, an engineer was given the responsibility for maintaining the records of plant performance and measurements. In addition, sophisticated examination techniques were in use in critical areas. The prime example at Dinorwig is the intermediate penstock (between the guard valve and the scroll case) and the scroll case. Every 2 years the passages are dewatered and semi-automatic, non-destructive testing of the welds is performed, the readings being automatically fed from the sensors

directly into the plant computer where they are compared with previous examinations. In this way, crack propagation is monitored in a critical area of the plant and remedial action can be instigated at the appropriate time.

The Japanese plants were operating with a procedure similar to U.S. plants, but well documented by the owners and standardized throughout their plants, and in all cases plant operators indicated very little unplanned downtime. A contributing factor is, of course, the strong domestic turbine and generator/motor manufacturing industry which enables manufacturers representation and technicians to be on site very quickly.

Staffing

Although a significant number of plants were intended to operate unmanned, very few have actually achieved that goal. Some plants are operating with restricted numbers of staff or are staffed during normal working hours. All plants, if manned, had trained operators available whether they were remotely operated or not.

COMMON PROBLEMS

Problems common in the pumped storage plants visited are described below, but generally included:

- Balancing line failure.
- Trashrack failure.
- Loose wedges.
- Vibration.

TURBINE PROBLEMS

General

The problems encountered with pump/turbine did not differ significantly from those occurring in conventional hydroturbines. The difference was only in severity. The many mode changes, starts, stops and reversal of rotation, puts an increased strain on the equipment. Also, the wicket gates and operating mechanism are subjected to greater load transients during the pumping cycle. Whereas it is not uncommon for a conventional hydroturbine to operate for 30 or 40 years without an overhaul, pump/turbines are overhauled every 10 to 15 years. Following is a summary of the problems encountered.

Cavitation

Although all pump-turbines are subject to cavitation damage, it is generally not considered a problem in the plants visited. As expected, there is less cavitation damage in stainless steel runners than those with stainless steel overlay. In the latter case, the amount of repair welding decreases with subsequent repairs and the extension of the stainless surfaces. An extreme example is Horse Mesa, where the amount of weld material required per year decreased from the initial 1,000 pounds to 10 pounds. There are many instances of cavitation damage to wicket gates and facing plates, which has prompted some plants to replace mild steel wicket gates with stainless steel ones. Some plants have used epoxy resin filler and coatings to delay the requirement for cavitation repairs.

Vibration

Many of the problems associated with the pumped storage plants visited were as a result of vibration or resulted in major vibration of units. Fracturing of balancing lines, excessive wear on linkages, the failure of bearing spider assemblies, the near flooding of Raccoon Mountain and other quoted examples all occurred during or as a result of heavy vibration. There are many reasons for excessive vibration, including misalignment, as at Castaic, inadequate bearing support as at Helms and unusual occurrences such as the thermal expansion of the shaft as at Fairfield.

Clearly attention must be directed in the future to the minimizing of the driving forces causing vibration and to increasing the ability of the turbine/generator and enclosing structure to dampen or absorb vibration. Though the vibrations can and do occur in conventional hydro plants, the problem of vibration is more acute in these machines since a significant proportion of pumped storage operating time is spent in "rough zones" while accelerating and slowing the units.

Runners

The most significant problem encountered with the runners was the cover plates over the flanges of split runners. These came loose and caused significant damage in four of the seven plants visited which have split runners. The usual cause was failure of the bolts holding them in place. The problem was corrected by welding the covers in place. Other solutions, such as filling the cavity with epoxy, was tried, but was not successful.

Wearing Rings

Wearing rings have also been a significant problem. The wearing ring failures have included falling off and seizure. At Wallace, the wearing rings seized, which resulted in a 16-month outage. At Bath County, a side load on the bearing caused by servomotor misadjustment resulted in a wearing ring seizure. The wearing rings came loose at six other plants, but no significant damage resulted. At Horse Mesa, an out-of-round wearing ring caused a bearing failure.

Bearings

Bearing failures have occurred for various reasons. Turbine guide bearings have failed because of side loads caused by servomotor imbalance and out-of-round wearing rings. Three plants had the turbine bearings lined with sprayed-on babbitt which came loose. All these bearings were changed to poured-in babbitt which has given better service.

Thrust bearings have failed due to misalignment, excessive downthrust, insufficient or uneven cooling and, in the case of Castaic, apparently a difference in loading caused by variation in the stiffness of the support springs caused the bearing to fail.

Wicket Gate Mechanism

Fifteen of the plants visited exhibited some problem with the wicket gates, journal bearings or the operating mechanism. The most common (eight instances) was washing out of the bearing grease due to lack of or failure of the seals. In these cases, seals were added or changed from square to quad or chevron type. Yards Creek has exhibited a greater number of shear pin failures, and both Smith Mountain and Salina have had progressive (cascade) failures. At Smith Mountain, this failure broke three gates. Wicket gates were also broken at Cabin Creek, when the runner failed. Castaic, Ludington and Dinorwig all had significant cavitation damage. Ffestiniog and, to a lesser extent Dinorwig, had peen marks on the inside of the contact point, the source of which is not known.

Balancing Lines

There were significant problems reported in connection with the balancing lines. Many plants have suffered cavitation in these lines and repairs and modifications have been completed with varying degrees of difficulty. Cavitation has sometimes occurred at the entrance, at elbows and around valves in the line. The most

difficult repairs concerned damage at elbows embedded in concrete. Among those plants reporting problems were Blenheim-Gilboa, Yards Creek and Bear Swamp.

Shaft Seals

The occurrence of problems with the shaft seals was relatively rare. The most serious failure was at Mt. Elbert where the holddown bolts came loose, which resulted in flooding the turbine pit. In general, it appears that mechanical seals have performed better than packing boxes.

GENERATOR/MOTOR PROBLEMS

Stator Windings

Several plants have had problems with stator windings, with seven or more plants rewinding the stators at least once. If the units had older Class B insulation, they were usually rewound with Class for H insulation, and in a few cases the units were uprated. The principal cause of winding degradation, or faults in a few cases, is insulation deterioration due to corona, temperature cycling and age. The type of duty, i.e., reversing and frequent starts as a motor, tends to shorten the life of the stator. Rewinding after about 10 years seems to be normal, although some units have been in service much longer than that without being rewound. At Lewiston and Blenheim-Gilboa, partial discharge analyzer equipment has been installed to monitor the condition of the windings, including detection of loose wedges.

Corona

Corona damage to the stator windings was limited, with two plants (Seneca and Yards Creek) having severe damage and seven others having some damage. Where the stators have been rewound, the corona problem has usually been improved.

Wedges

Loose wedges have been a problem in the majority of installations. Most units are checked for loose wedges during every scheduled maintenance period. In a few machines, some wedges dropped out of the slots. At one plant, the wedges were tight but the coils behind them were not properly installed and became loose. Several plants have been using the corrugated (expandable) wedge backing strips with good results, although the time-in-use is still short.

Alignment and Movement

Two plants, Castaic and Cabin Creek, have had bearing problems and have expended considerable effort to obtain nearly perfect vertical alignment of shafts in order to minimize their bearing difficulties. At Castaic, the last unit to be overhauled was aligned to within $\pm.002$ inches, using optical alignment equipment. Other plants have not experienced a continuing problem with vertical alignment but several use or recommend the use of optical alignment equipment.

Cooling

Cooling equipment has not been a major problem at most plants. Leaks have occurred in the coolers or piping at several plants. One plant has had fouling of both the inside and outside air coolers and has to clean them annually. Raccoon Mountain is the only plant with water-cooled stators and rotors and has had some trouble due to water leakage, including one water-caused fault in the stator. The operators watch for signs of leakage and instruments are provided to detect leakage above a set point. The operators are considering resetting the instrumentation to make it more sensitive because of the serious damage that can occur during a rotor or stator water leak.

ANCILLARY EQUIPMENT PROBLEMS

Starting Equipment

Starting equipment, in general, has had few problems. Those plants that have electronic frequency converters have been trouble-free, except for the startup problems at Mt. Elbert. Pony motors for starting have also been trouble-free, except for routine brush and bearing maintenance. Reduced-voltage equipment has had little trouble except at one plant, Yards Creek. The starting reactors had to be replaced twice due to their under-rated design.

Unit Circuit Breakers

The piece of equipment that has exhibited continuing problems at the largest number of plants is the unit circuit breakers, whether at generator/motor or switchyard voltage. The manufacturer's design criteria for circuit breakers evidently underestimated their heavy duty and frequent operation in a pumped storage plant. A typical circuit breaker duty requires about 1,000 close-open (C-O) operations a year. The older designs had a rated life of 250 to 300 C-O operations and some of the newer ones 2,000 to 3,000 C-O operations. Thus, the best of them have a rated life of two to three years in a pumped-storage plant.

Constant maintenance is often required. In a few plants, the breakers are given a thorough (take-down) inspection monthly. In others this is done every 3 months, or after about 300 C-O operations. Almost every plant overhauls all its circuit breakers and switches used for starting and controlling the units every year, changing contacts, springs, arc chutes, and other parts as necessary. Even those plants with the newer SF_6 or vacuum breakers, rated 2,000 to 3,000 C-O operations, usually inspect and test the breakers during their scheduled unit overhauls.

Replacement parts have always been a problem. At best, they are expensive and have long delivery time, often up to 18 months. At worst, the parts are no longer available from the equipment manufacturer. This was the usual case for plants built 20 to 30 years ago. These plants have to fabricate their own parts or scavenge them from surplus units. Several plants with the older type circuit breakers have replaced them with SF_6 or vacuum breakers and have been getting much better service as a result.

Control Systems

The plant control systems, in general, have not been a major operation problem. The nature of the equipment is such that functional problems have to be worked out during construction and commissioning, or the plants cannot be put into service. Following this, it is usually single components that fail to work properly and have to be replaced, often with a different type device that will do the same function. This would include devices such as level switches, temperature detectors, data transmitters and such. In one plant, a computer that had worked well over a long life was to be replaced with a new one that had greater capabilities.

Hard wire systems in some plants have been confusing to maintenance staff because the systems were built for many modes of operation and yet have only been used in a few of them. There is, therefore, extensive "redundant" wiring which complicates and delays repair.

There was a general desire to upgrade the control systems, especially that portion that communicates and interfaces with remote dispatch centers.

Air Systems

There were only two problems mentioned that related to the air system. The most serious was actually a design problem in that the system capacity of some plants was not sufficient to meet the blowdown air requirements for starting as pumps with the frequency desired by the dispatcher. In one case, the storage capacity is

being increased. The other problem mentioned was in two plants where the water level control switches gave problems. At Bath County, splash caused faulty operation and at Mt. Elbert, a modulating system did not work properly. In several plants, it was desired to suppress turbine vibrations by injecting air into the water passages. However, the air supply was insufficient for extended operation. This problem is no different than in conventional hydro plants in which the turbines are set too low to draw air at atmospheric pressure.

Transformers

Transformers have been generally trouble-free, but when problems have occurred, it has been very time-consuming and expensive to repair. The extreme example is Blenheim-Gilboa, where gassing and an internal fault occurred in one transformer. It was repaired and returned to the factory twice for repair. Next a new transformer was purchased. It was damaged in shipment and had to be returned to the overseas factory for repair and return. Total elapsed time was over five years and the transformer was still not in service. Fortunately, a spare transformer had been provided, so it was not necessary to curtail plant operation.

Gassing occurred at four plants, water getting into the winding caused one failure, a few bushing failures and some other types of failures. Where the failures required transformer removal and factory repair, highway and transportation restrictions have caused trouble. Jocassee had to ship several transformers back to the factory for repair following gassing, and the roads over which they had to be transported were very difficult to traverse.

Valves

Of the 22 spherical and straight flow valves inspected, eight have had problems with the movable seals being wiped. Other problems have included galling of the operating cylinder and corrosion of the body at the seals at Dinorwig and opening of the seal during construction at Northfield, which resulted in the flooding of the plant. Many plants suffer from excessive seat ring leakage.

CIVIL AND HYDRAULIC PROBLEMS

By their nature, a large proportion of the investment in a pumped storage scheme is in the civil and hydraulic works. That being so, and although much of the civil works are subject to cyclic loading, the incidence and severity of continuing civil and hydraulic problems in operating projects is remarkably low. Almost all the plants visited had experienced major problems during the civil construction but the number of plants that had experienced significant problems during operation was far

less. Very few plants were suffering a recurring problem or one that determined the frequency of maintenance outages. Almost invariably civil repairs were carried out at times determined by the repair scheduling of mechanical or electrical components. It is beyond the scope of this report to present construction difficulties, most of which were the subject of technical papers, so only the problems of a civil engineering nature that have occurred during operation are presented below.

Upper Reservoirs and Dams

The incidence of significant leakage, which have required continuous measurement or repair, are not confined to a particular type of construction. Plants that have reported leakage include Seneca, Ludington and Nummapara, which have asphaltic liners; Muddy Run, Salina and Taum Sauk, which utilize concrete liners; and Yards Creek, Jocassee, Carters and Mt. Elbert, all of which used processed natural materials.

The most significant remedial measures were taken at Mt. Elbert where after a history of leakage, an impermeable sheet of Hypalon was laid over the whole of the interior of the upper reservoir. The other plant that had to make substantial repairs was Seneca, which suffered leakage in the depression that forms the reservoir floor. The floor itself was not originally sealed with asphalt but a polyethelene vinyl coated (PVC) liner was installed over 10 acres of the reservoir floor during these remedial works and finally the entire floor was covered with asphalt.

The original asphalt lining of the reservoir embankment has suffered cracking from time to time but the frequency of occurrence has diminished with the size of the leak. At no time was cracking or sink holes in the asphalt considered serious enough to affect the operating schedule. The cracks were repaired as soon as they were discovered.

At Ludington, the failures in the asphalt lining were more serious and prompted a full series of remedial measures. Two separate failures of the lining occurred, one near the intake due to excess water pressure below the lining, and one involving shear of the lining due to failure of the calcereous sand support.

Muddy Run and Salina are both exhibiting continuing leakage from the intake channels, which are lined with concrete slabs with mastic joints. Leakage in both cases has been traced to the concrete joints and to cracks in the concrete liner. It was reported at Salina that the reason for the cracking is washing the fines

through joints from behind the concrete liner. When the channel is filled with water after drawdown, a crack occurs. In both plants, regular maintenance is required to ensure that all joints (and cracks) are filled with sealant. In addition, at Salina, migration of water through the left embankment to the intake channel has led to the decision to install a slurry trench. Taum Sauk, which features an artificial upper reservoir, has developed leakage through the asphalt covered floor, the toe of the embankment, which is existing rock covered with sprayed mortar, and the joints in the concrete face. Remedial measures have included grouting and cutting out of joints for repatching, which has reduced seepage dramatically. However, continuous maintenance will undoubtedly be necessary because the reservoir embankments were unconsolidated rockfill and subject to much movement upon loading.

The other plants mentioned have upper reservoirs and dams formed by relatively unprocessed materials. Yards Creek Dam leaked, probably because of penetration of the filter into the core. Jocassee's leakage has occurred at both abutments through undisturbed material and remedial measures have included the excavation of abutment material and replacement by a controlled engineered fill. A program of monitoring is in progress. Carters has exhibited small leaks.

Most embankments have performed within the predictions, but San Luis experienced an embankment upstream slip because of a foundation failure.

<u>Penstock, Hydraulic Passages and Appurtenances</u>

Generally, performance of the U.S. pumped storage schemes has been excellent, with no excessive hydraulic transient effects reported anywhere.

The most common problems associated with trashracks and incidences were reported at Muddy Run, Smith Mountain, Salina, Mt. Elbert, Mormon Flat, Horse Mesa, Taum Sauk and Ludington. At Muddy Run, the von Karman effect caused a trashrack vibration, which was cured by welding a bracing on the large trashracks. At Salina, a similar solution was used when the upstream trashrack failed when pumping. The trashrack again failed after the repair. It was finally discovered that the spacing of bars on the upstream rack was smaller than that on the downstream rack, thus allowing the debris to clog the upstream rack on the inside during pumping. The problem became more serious, however, in that the parts of the failed trashrack were swept into the adjacent penstock and became lodged in the turbine. Finally, the upstream trashracks were modified to include a larger bar spacing.

At Smith Mountain, the upstream trashracks failed during pumping and the staff modified them so that they would be raised during pumping.

The difficulties at Mt. Elbert and Ludington have centered on the draft tube trashracks. At Mt. Elbert, the racks on unit No. 2 draft tube have been destroyed and are currently on order. It is suspected that the draft tube pressure oscillations have caused the problem and solutions are being sought. At Ludington, no failures have occurred, but very occasionally during winter pumping, frazil ice clogs the trashracks, threatening damage. Reversal of the flow for few minutes solves the problem.

Occasionally plants have reported difficulty with the gates. In particular, Fairfield was experiencing vibration of both upstream and downstream gates. This may have been because the gates were designed to hang submerged when dogged. The gates vibrated severely during the plant operation and eventually broke loose. After a downstream gate fell down during pumping, all gates were modified to dog them as high as possible. Fairfield is also disappointed in the performance of their J-seals on the bottom of the gates. Bear Swamp had one incident with a gate which was lifted by the air blown into the draft tube. As the gate dropped again, the suspension cables snapped, dropping the gate to the draft tube bottom.

Only two plants, Bath County and Taum Sauk, reported major problems with penstocks, although Seneca and Yards Creek have also had to perform remedial work. The substantial regrouting of the high pressure tunnels at Bath County has been explored in many technical papers and reports, but it is worth noting that even after the work, the plant staff feel that the maintenance criteria will need to be modified. Contrary to the original intention, it is now believed that penstocks cannot be unwatered in isolation, and that future drawdown will have to be more carefully performed than originally intended. Taum Sauk has a recurring incidence of the outside penstock drains being blocked with calcium carbonate as a result of a high calcium content spring. Upon drawdown, buckling occurs in the steel penstock liner. A roto-rooting device is used to clear the drains.

At Seneca, after the first filling the concrete lining of the penstock cracked more severely than expected and remedial grouting work was necessary. At Yards Creek, it was necessary to regrout the junction between the tunnel and the steel aboveground penstock after a few years of operation.

Few comments were offered on the performance of the spherical valves. The most serious incident occurred at Northfield during the plant handover when the powerhouse flooded, but there have been no similar occurrences during operation. At Raccoon Mountain, the vibration evident during early use of the machines was blamed for the loosening of a number of flange bolts on the spherical valve bypass. There is no doubt that this particular incident came close to causing a powerhouse flooding but for prompt action by the staff. Also at Raccoon Mountain, the condition of valve seals has led the operators to inject horse manure into the penstock upstream of the valve when the valve is closed to maintain the seal. This is only necessary when the scroll case is open and maintenance work is underway.

Blenheim-Gilboa reported slow pressure pulsations in the penstock due to slight leakage around one of the spherical valves.

Draining and Filling

Draining and filling of the upper reservoir and penstock has been necessary in many of the older schemes. For schemes in which there were no isolating penstock gates, draining involved problems. At Northfield, draining the upper reservoir for penstock inspection drew in a large quantity of silt and fish (picked up from the bottom of the reservoir) into the high pressure tunnel. Draining at Taum Sauk and Bath County resulted in tunnel liner collapse. With almost all plants, complete draining results in difficulties in refilling because pump turbine manufacturers restrict the use of the unit in the pumping mode below minimum head. At least two plants (Numappara and Turlough Hill) included filling pumps so that the whole hydraulic system could be drained and refilled with ease. The ability to drain and fill the upper pool facilitates the inspection of its impervious lining. At Turlough Hill, the runner in the filling pump, which is optimized for pumping, could be replaced with a runner optimized for turbine performance so that the unit could assist in a black start. Some plant operators admitted that they had refilled the penstock by starting a unit against zero head, a practice which manufacturers would probably condemn.

Flooding

The worst case of flooding occurred at Northfield while the plant was being prepared for handing over to the Owner. The valve in the drain line for the turbine shutoff valve seal control valve was accidentally left in the closed position. This caused the control valve to drift to the open position, thus opening the main valve seals. Leakage from the penstock past the seals was able to spill into the powerhouse through an open access mandoor in the draft tube. Luckily, the upper

reservoir, which cannot be isolated, did not contain any water, but the flooding from water in the penstock completely covered the generator/motor, necessitating expensive cleaning.

Yards Creek suffered two floodings, one from an equalizer line break and one resulting from human error.

Raccoon Mountain suffered a near flooding when the turbine shutoff valve bypass pipework became loose. This would have been a very serious occurrence because the upper reservoir, which also cannot be isolated, was full at the time.

Apart from the three cases described above, there is a danger of substantial damage or danger from less severe flooding. At Blenheim-Gilboa, the provision of a small drain line, which could not pass the incoming water from a strainer failure, would have been a relatively minor detail except that the switchboards that controlled drainage pumps could be deenergized only by walking through the floodwater.

It was noted in France that EDF had suffered three major floods in hydro plants and a task force was working on the preparation of design criteria and details to minimize the chance of another case.

GENERAL CONCERNS

Spare Parts

The problem of spare parts was raised at many of the plants visited. The main concerns related to the availability of spare parts and the time for delivery. A substantial number of the plants had experienced frustrating delays in obtaining spare parts, often because the equipment in the plants had been superceded and parts were no longer held "on the shelf" by manufacturers or because the stateside manufacturers were having parts made overseas. In one particular case, replacement wicket gates were cast and machined in Japan (by the choice of the turbine manufacturer who was not Japanese) and, because of communication difficulties, an incorrect template was used. The error was not noticed until the units had been reassembled, at which time the gates would not close.

Some operators raised the problem of shop drawings. They felt that they had not received sufficiently detailed spare parts shop drawings that could be used for competitive bids. This became more of a problem when parts or systems were withdrawn from production. It was suggested that when a particular item was dropped from the manufacturer's product line or after a set period of (say) 10 years, more

detailed shop drawings should be made available to previous purchasers for the use at competitive bids for replacements. This requirement could be included in contract documents. Plants would thus be able to build up stocks of spare parts, based on their own experience of requirements, to be used on short notice.

Each plant was canvassed for recommendations on major spare parts, which should be held at the plant. One suggestion was that spares should be carried for anything that takes more than 30 days for delivery but a recommended list would tend to include:

- Wicket gates.
- Wicket gate arms and linkage (20% of total).
- Wicket gate shear pins.
- Wicket gate servomotor.
- Wicket gate bushings (one per unit).
- Turbine wearing rings.
- Turbine seal ring.
- Packing sleeve.
- Packing.
- Thrust bearing.
- Guide bearing (one of each).
- High pressure pump for bearing oil.
- Seating rings for turbine shutoff valve.
- Internal parts for turbine shutoff valve bypass line valves.
- Rotor coil and winding materials.
- Stator coil and winding materials.
- Cooler tubes for large applications.
- Coolers for small applications.
- Miscellaneous governor parts.
- Packing and discs for all valves (except for turbine guard valves).
- Spare valves for special applications.
- Circuit breakers for generator/motor.
- Multiple sets of contacts, coils and springs.

- Wedges.
- Wedge packing material.
- Main transformer.
- Bushing.

This list does not include smaller items and would eventually be modified by each individual plant, depending on water quality, type and degree of station usage (normal or synchronous condenser), method of overhaul scheduling, etc.

With regard to templates for the wicket gates and runner blades, few of the plants possessed them. One or two plants that have templates available, used them for weld-cladding and finishing. Another approach taken by some plants was accepting that there is some deficiency in manufacturing control, and making templates from the blade exhibiting least cavitation damage to use these templates for repair of other blades. Where this approach has been used, it has sometimes been successful in reducing cavitation, but no measurements were available to prove that an increase in efficiency had resulted.

Capital Expenditure vs. Maintenance

During the design process, there are strong pressures on the designers to limit the cost of a project by minimizing the space in a powerhouse. Although it is difficult to quanitify the result, it was clear that in a number of the plants visited, space restrictions were serious, particularly during overhaul. Such restrictions tended to occur in underground plants. Clearly, at the design stage, the operating staff should have substantial input to the general arrangement and design criteria.

At plants that have no facilities for isolating the upper reservoir (and therefore no convenient method for emptying or filling the tunnels and penstocks), the staff inevitably pointed out that inclusion of such a capability would significantly lessen maintenance time.

Many plants, particularly those with few units, were operating with significant space restrictions, particularly when major overhauls were required because of the limited size of their powerhouses. At Bear Swamp, a two-unit underground station that was undergoing overhaul of one of the units when we visited, the whole powerhouse was overwhelmed with parts from the dismantled machines. It is probable that this would contribute to a slow overhaul. Some powerhouses appeared to have sufficient room but exhibited design that unnecessarily complicate maintenance. In

Northfield, which is a relatively small installation, a runner cannot be turned over except by being brought out of the powerhouse and into the access tunnel.

Outdoor and semi-outdoor powerhouses, although not lacking the laydown area, were often criticized for the lack of weather protection. Most major servicing tends to be done in the spring or fall when both the air conditioning and heating loads are low. At this time, rain is common and an arrangement such as that at Lewiston, where a covered area is available, was deemed desirable. With respect to areas within the powerhouse, the most difficult areas to work in tend to be around the turbine head cover and generator/motor. Two powerhouses viewed, Dinorwig and Turlough Hill, had intermediate shafts and machine galleries serviced by cranes under the generator/motors and the staff at both were very pleased with the arrangement. In both cases, access to the head cover, wicket gate operating mechanism and seals was very easy for normal maintenance and for overhaul. If necessary, the runner could be removed without removing the generator/motor rotor. All other plants exhibited a rather cramped chamber above the head cover, with restricted access. At Montezic, removal of the runner is from below the unit, by means of removable section of the draft tube. As yet, no runner has been removed.

The question of transformer access arose from time to time. In Ludington and Blenheim-Gilboa, the transformers had to be removed surprisingly often and a simple problem such as the inability to use the plant crane became a significant extra cost in maintenance. In other plants, such as Raccoon Mountain, well thought out and relatively expensive arrangements (a separate transformer cavern) had not yet been justified by the amount of maintenance required.

Construction Management

There were three cases examined in which construction management was mentioned during the discussions. In the case of Dinorwig, the construction contract for the main works had been let as a "target price plus variable fee" and this proved to be an unwieldy method of administering such a large contract. No opinion was sought or given as to the advisability of such a contract on a large and complex project, but it should be noted that geological uncertainties and a relatively fast track approach necessitated some contract arrangement other than the normal.

Some experiences in the U.S. also indicate that substantial effort and investment in construction management, whether by the utilities themselves or by engineering consultants, can make a major contribution to the quality of the end product.

Appendix A

PLANT DATA SUMMARY

Appendix A consists of a list of factual data for each of the plants that were studied for this report. Plant data, though not exhaustive, does give an indication of the size and composition of each project and, as far as possible, has been checked by each owner utility.

FILE PLTDT100.WK1

APPENDIX A
SHEET 1

PROJECT DATA SUMMARY
TABLE 1
GENERAL PLANT DATA

NAME	RIVER OR WATER SOURCE	STATE	COUNTY (TOWN)	OWNER	PLANT'S CITY/STATE/ZIP	PLANT'S STREET ADDRESS
DOMESTIC PROJECTS						
BATH COUNTY	BACK CREEK	VIRGINIA	BATH	VA. ELEC. & POWER CO. (VEPCO) / ALLEGHENY POWER SYSTEM	WARM SPRINGS, VA. 24484	BATH COUNTY PUMPED STORAGE STATION
BEAR SWAMP	DEERFIELD RIVER	MASSACHUSETTS	BERKSHIRE (ROWE)	NEW ENGLAND POWER CO.	READSBORO, VT. 05350	P.O. BOX 218
BLENHEIM GILBOA	SCHOHARIE CREEK	NEW YORK	SCHOHARIE	NEW YORK POWER AUTHORITY	GRAND GORGE ,NEW YORK 12434	10 COLUMBUS CIRCLE
CABIN CREEK	SOUTH CLEAR CREEK	COLORADO	CLEAR CREEK (GEORGETOWN)	PUBLIC SERVICE CO. OF COLORADO	DENVER, COLORADO 80202	550 15TH ST.
CARTERS	COOSAWATTE RIVER	GEORGIA	MURRAY (CARTERS)	U.S. CORP OF ENGINEERS	CHATSWORTH, GA. 30705	RTE 3, BOX 165-C
CASTAIC	W. BRANCH CA. AQUEDUCT	CALIFORNIA	LOS ANGELES (CASTAIC)	LOS ANGELES DEPT. OF WATER AND POWER	LOS ANGELES, CA. 90051	111 N. HOPE ST. BOX 111
FAIRFIELD	BROAD RIVER	SOUTH CAROLINA	FAIRFIELD (PARR)	SOUTH CAROLINA GAS & ELEC.	JENKINSVILLE, S.C. 29065	P.O. BOX 57
HELMS	W FORK KINGS RIVER	CALIFORNIA	FRESNO	PACIFIC GAS & ELEC.	SHAVER LAKE, CA. 93664	57800 ,Mc KINLEY GROVE RD.
HORSE MESA	SALT RIVER	ARIZONA	MARICOPA	SALT RIVER PROJECT POWER DISTRICT	PHEONIX, AZ. 85072	P.O. BOX 52025
JOCASSEE	KEOWEE RIVER	SOUTH CAROLINA	PICKENS (SALEM)	DUKE POWER CO.	CHARLOTTE, NC. 28242	P.O. BOX 33189
LEWISTON	NIAGARA RIVER	NEW YORK	NIAGARA (LEWISTON)	NEW YORK POWER AUTHORITY	NIAGRA FALLS, NY, 14302	P.O BOX 277
LUDINGTON	LAKE MICHIGAN	MICHIGAN	MASON (LUDINGTON)	CONSUMERS POWER CO. & THE DETROIT EDISON CO.	LUDINGTON, MICHIGAN 499431	3525 S. LAKESHORE DR.
MORMON FLAT	SALT RIVER	ARIZONA	MARICOPA (TORTILLA FLAT)	SALT RIVER POWER DISTRICT, ARIZONA	PHEONIX, AZ. 85072	P.O. BOX 52025
MOUNT ELBERT	MT ELBERT CONDUIT	COLORADO	LAKE (TWIN LAKES)	U.S. BUREAU OF RECLAMATION	GRANITE, COLORADO 81211	GRANITE STAR ROAD
MUDDY RUN	SUSQUEHANNA RIVER	PENNSYLVANIA	LANCASTER(DRUMORE)	PHILADELPHIA ELECTRIC CO.	PHILADELPHIA, PENN. 19101	2301 MARKET ST.
NORTHFIELD MOUNTAIN	CONNECTICUT RIVER	MASSACHUSETTS	FRANKLIN(ERVING)	NORTHEAST UTILITIES	NORTHFIELD, MASS. 01360	RR1, BOX 377
RACCOON MOUNTAIN	TENNESSEE RIVER	TENNESSEE	MARION (CHATTANOOGA)	TENNESSEE VALLEY AUTHORITY	CHATTANOOGA, TN. 37401	CHESTNUT ST. TOWER II
SALINA	GRAND RIVER	OKLAHOMA	MOYES	GRAND RIVER DAM AUTHORITY, OKLAHOMA	VANITA, OKLAHOMA 74301	P.O. BOX 409
SAN LUIS	CA. AQUEDUCT	CALIFORNIA	MERCED	U.S. BUREAU OF RECLAMATION	SACREMENTO, CA. 95814	1416 NINTH ST.
SENECA	ALLEGHENY RIVER	PENNSYLVANIA	WARREN	PENN. ELEC. CO. / CLEVELAND ELEC. ILLUM. CO.	WARREN, PA. 16365	BOX 126
SMITH MOUNTAIN	ROANOAKE RIVER	VIRGINIA	PITTSYLVANIA	APPALACHIAN POWER CO., VIRGINIA	ROANOKE, VA, 24022	40 FRANKLIN ROAD SW P.O. BOX 2021
TAUM SAUK	BLACK RIVER	MISSOURI	REYNOLDS (ELDON)	UNION ELECTRIC CO. OF MISSOURI	ST. LOUIS, MISSOURI 63103	1901 GRATIOT ST.
WALLACE	OCONEE RIVER	GEORGIA	HANCOCK (EATONTON)	GEORGIA POWER CO.	EATONTON, GA. 31024	P.O DRAWER 630
YARDS CREEK	YARDS CREEK	NEW JERSEY	WARREN (BLAIRSTOWN)	JERSEY CENTRAL P&L/PSE&G	BLAIRSTOWN, N.J. 07825	P.O. BOX L
FOREIGN PROJECTS						
DINORWIG	AFON PERIS	UK (WALES)	GWYNEDD	CENTRAL ELECTRICITY GEN. BOARD	GWYNEDD LL55 4TY	LLANBERIS
FFESTINIOG	NONE	UK (WALES)	GWYNEDD	CENTRAL ELECTRICITY GEN. BOARD	BLENAU FFESTINIOG	TAN-Y-GRISIAU
TURLOUGH HILL	LOUGH NAHANAGAN	IRELAND	GLENDALOUGH	ELECTRICAL SUPPLY BOARD OF IRELAND	CO WICKLOW, EIRE	GLENDALOUGH POST OFFICE
LE TRUEL	TARN RIVER	FRANCE	AVEYRON	ELECTEICITE' DE FRANCE	CHAMBERY FRANCE	REAL.BP.1034 73010 CHAMBERY, CEDEX
MONTEZIC	TRUYERE RIVER	FRANCE	AVEYRON	ELECTEICITE' DE FRANCE	MARSEILLE, FRANCE	REAM.BP.560 13401 MARSEILLE, CEDEX
BAJINA BASTA	RIVER DRINA	YUGOSLAVIA		ZOROZENA ELEKTROPRIVREDA		
MINGHU	SHUILI RIVER	TAIWAN	NANTU	TAIWAN POWER CO.	SHUILI, NANTOU, ROC	55399 SHUILI
NUMAPPARA	NAKA RIVER	JAPAN	TOCHIGI	ELECTRIC POWER DEVELOPMENT CO.	KUROISO, TOCHIGI	ITAMURO, KUROISO CITY
SHINTOYONE	OHNYU RIVER	JAPAN	AICHI	ELECTRIC POWER DEVELOPMENT CO.	KITASHITARAGUN, AICHI	KOMADATE, TOYONEMURA
MASEGAWA		JAPAN		CHUBU ELECTRIC POWER CO.		
OKUYAHAGI PLANT 1		JAPAN		CHUBU ELECTRIC POWER CO.		
OKUYAHAGI PLANT 2		JAPAN		CHUBU ELECTRIC POWER CO.		

FILE PLTDT200.WK1

PROJECT DATA SUMMARY
TABLE 2
CONSTRUCTION DATA

APPENDIX A
SHEET 2

NAME	MAIN CONTRACTOR	MAJOR SUBCONTRACTORS (OTHER CONTRACTORS)	CONSULTING ENGINEERS	CONSTRUCTION TIME (YRS)	YR. FIRST IN SERV.	CONSTRUCTION COSTS ($1000)	CAPACITY (MW)	COST PER KW ($) INSTALLED	COST PER KW ($) 1988$
DOMESTIC PROJECTS									
BATH COUNTY	DANIELL CONSTR	CLEMETRIC/GATES & FOX	HARZA ENG. CO.	8	1,985	1,700,000	2,682	634	755
BEAR SWAMP	JA. JONES	WISMER & BECKER	CHAS. T. MAIN OF NEW YORK	3	1,974	105,899	600	176	399
BLENHEIM GILBOA			CHAS. T. MAIN OF NEW YORK	4.5	1,973	153,293	1,000	153	367
CABIN CREEK	JONES/HARRISON	MARTIN K EBY	STONE & WEBSTER	3	1,967	37,418	300	125	424
CARTERS	AL JOHNSON/KIEWIT	CLEMENT BROS/KANDY INC		13	1,977	107,000	750	143	271
CASTAIC			DEPT OF WATER & POWER		1,973	317,037	1,275	249	596
FAIRFIELD	DANIEL CONSTRUCTION	CLEMENT BROS	GIBBS & HILL	4	1,978	201,549	511	394	706
HELMS	WISMER BECKER-GUY F ATKINSON	GRANITE-BALL-GROVES	N/A	8	1,984	980,000	1,053	931	1,175
HORSE MESA	BECHTEL	NONE	BECHTEL		1,972	22,952	366	63	159
JOCASSEE				7.5	1,973	107,000	612	175	419
LEWISTON	TUSCARORA CONTRACTORS		CHAS. T. MAIN OF BOSTON,	3	1,961	632,485	240	2,635	12,709
LUDINGTON	EBASCO ENGINEERING CORP.	MK/STRABAG (KEN LARSON)	EBASCO ENGINEERING CORP.	4	1,973	308,726	1,872	165	395
MORMON FLAT	BECHTEL	NONE	BECHTEL		1,971	16,205	86	188	507
MOUNT ELBERT					1,985		200		
MUDDY RUN				2	1,967	83,834	800	105	356
NORTHFIELD MOUNTAIN	MORRISON-KNUDSEN		STONE & WEBSTER ENG. CORP.		1,972	126,549	846	150	380
RACCOON MOUNTAIN				8	1,979	334,000	1,530	218	369
SALINA			HOLWAY		1,968	29,922	260	115	369
SAN LUIS		MORRISON-KNUDSON	USBR	4	1,968	61,692	388	159	510
SENECA	HUNKIN-CONKEY	WARREN BROS	HARZA ENG. CO.	3	1,969	66,193	422	157	475
SMITH MOUNTAIN	SOLLITT CONSTRUCTION		AEP/EBASCO ENGINEERING	3.5	1,965	88,684	565	157	600
TAUM SAUK	FRUIN COLNON/UTAH CORP	NOOTER CORP	SVERDRUP & PARCEL ENG	3	1,963	45,854	408	112	482
WALLACE	MID-SOUTH CONST.	CLEVELAND ELECT.	GEORGIA POWER/SOUTHERN SERVICES		1,979	204,007	321	636	1,074
YARDS CREEK	C.J.LANGENFELDER SONS	WM BLANCHARD CO	EBASCO SERVICES INC.		1,965	32,879	330	100	381
FOREIGN PROJECTS									
DINORWIG	MACALPINE/BRAND/ZSOKKE	GLEESON	JAMES WILLIAMSON/BINNIE		1,982		1,550		
FFESTINIOG	McALPINE/CLEMENTS		JAMES WILLIAMSON/FREEMAN FOX		1,961	19,500	360	54	261
TURLOUGH HILL			ESB/LAHMEYER	5.5	1,974	30,424	292	104	236
LE TRUEL			EDF		1,982		40		
MONTEZIC			EDF		1,982		912		
BAJINA BASTA					1,979		348		
MINGHU	ASEA/BES/ET AL.		EPDC		1,984		1,000		
NUMAPPARA	HITACHI		EPDC	4	1,973	201,666	675	299	716
SHINTOYONE	TOSHIBA		EPDC	4	1,972	284,066	1,125	253	641
MASEGAWA							288		
OKUYAHAGI PLANT 1							343		
OKUYAHAGI PLANT 2							783		

PROJECT DATA SUMMARY
TABLE 3
PLANT OPERATION

NAME	NUMBER OF REV. TURB	CONV UNITS NO/MW	TOTAL GENERATION CAPACITY (MW)	TIME %	ENERGY MWHRS/YR	PLANT FACTOR	PUMPING INPUT (MW)	TIME (%)	ENERGY MWHRS/YR	PUMP FACTOR	SYNCH. CONDENSING INPUT (MW)	TIME (%)	MWHRS/YR TOTAL	GENERATING TO PUMPING RATIO	STORED ENERGY (MWH)	GOV SPEED DROOP (%)	NORMAL OPERATION DESCRIPTION	AV NO MODE CHANGES PER DAY	BRAKING SPEED %
DOMESTIC PROJECTS																			
BATH COUNTY	6		2,682	12.8	2,241,330	9.5	2,460	14.2	3,000,000	13.9	54.0	4.4	20,700	0.75	23,700	BLOCK	DAILY CYCLE	8	12
BEAR SWAMP	2		600		395,595	7.5	618		583,006		N/A	0.0	N/A	0.68	3,690		DAILY CYCLE		9
BLENHEIM GILBOA	4		1,000	24.0	1,953,328	22.3	1,088	29.7	2,917,700	30.6	24.0	0.3	706	0.67	12,000	4	DAILY CYCLE	6	4
CABIN CREEK	2		300	4.9	64,713	2.5	300	4.7	99,763	3.8	3.7-4	1.0	10,426	0.65	1,450	BLOCK	DAILY CYCLE	6	3
CARTERS	2	2/250	750	3.9	95,274	1.5	258	18.7	462,638	20.5	N/A	NIL	N/A	0.21	6,245	5	DAILY CYCLE	6	13
CASTAIC	6		1,275	10.7	N/A		1,410	3.0	N/A		3.5-4	8.3	N/A	0.67	12,000		SYNC COND	6	12
FAIRFIELD	8		511	11.9	466,836	10.4	572	12.8	659,740	13.2	5	NIL	N/A	0.71	4,096		DAILY CYCLE	2	15
HELMS	3		1,206	18.0	595,137	5.6	1,029	14.0	958,498	10.6	N/A	N/A	N/A	0.62			DAILY CYCLE		4
HORSE MESA	1	3/93	366				86							0.50	620	BLOCK	DAILY CYCLE		
JOCASSEE	4		612	(1) 37.7	1,162,000	21.7	709	34.2	1,479,000	23.8		NIL	N/A	0.79	32,000	5	DAILY CYCLE		15
LEWISTON	12		240	7.7	194,892	9.3	345	8.9	315,905	10.5	N/A	0.0	N/A	0.62		BLOCK	(1)	4/5	
LUDINGTON	6		1,872	18.8	2,640,000	16.1	1,980	20.4	3,695,000	21.3	20		4,880	0.71	15,000	BLOCK	WEEKLY CYCLE		10
MORMON FLAT	1	1/44	86	22.0	104,170	13.8	48	11.0	124,662	29.6		0.0		0.84	287	BLOCK	DAILY CYCLE		36
MOUNT ELBERT	2		200				257								3,200		DAILY CYCLE	1	10
MUDDY RUN	8		800	30.8			814	32.0	1,500,000	21.0	N/A	0.0	N/A	0.71	11,800	5	DAILY CYCLE	4 to 8	50
NORTHFIELD MOUNTAIN	4		846				868				N/A	0.0	N/A	0.73	8,500	BLOCK			
RACCOON MOUNTAIN	4		1,530	10.5	1,292,160	9.6	1,631	13.4	1,637,544	11.5		3.0		0.79		5	DAILY CYCLE	9.7	2
SALINA	6		260				292				N/A	0.0	N/A			BLOCK	DAILY CYCLE		20
SAN LUIS	8		388	18.0			388	72.3			N/A	0.0	N/A	0.67	465,000	BLOCK	SEASONAL		20
SENECA	2	1/26	422	22.1	586,000	15.9	396	20.6	812,000	23.4	N/A	0.0	N/A	0.72	4,200	5	DAILY CYCLE	4 to 14	11
SMITH MOUNTAIN	3	2/160	565	7.4	435,200	8.8	279	14.2	490,000	20.0	13	57.2	5,080	0.89	26,656	5	DAILY CYCLE	up to 12	28
TAUM SAUK	2		408	(2) 0.5	14,000	0.4	408	1.4	45,400	1.3	N/A	0.0	N/A	0.31	2,700	BLOCK	(2)		15
WALLACE	4	2/56	321	11.7	347,172	12.3	248	19.5	419,545	19.3				0.83	2,130,000	5	PEAKING		30
YARDS CREEK	3		330	21.8	571,041	19.8	420	24.5	859,251	23.4	N/A	0.0	N/A	0.66	2,850	BLOCK	DAILY CYCLE	6	12
FOREIGN PROJECTS																			
DINORWIG	6		1,550		1,823,000	13.4	1,800		2,664,000	16.9			96,000	0.68		1	DAILY/SYNC COND	40	DYNAMIC
FFESTINIOG	4		360	11.4	328,146	10.4	300	17.7	502,103	19.1	7	54.4	33,000	0.65	1,358	BLOCK	DAILY/SYNC COND	27	25
TURLOUGH HILL	4		292		369,764	14.5	273		567,265	23.7		NONE	N/A	0.65	1,540		DAILY/SYNC COND	6	
LE TRUEL	1		40				36					0.0	N/A			5			5
MONTEZIC	4		912				872							0.75	30,000	5	WEEKLY/SYNC COND		5
BAJINA BASTA	2		348									NIL	N/A			4		6	3
MINGU	4		1,000				1,076					NIL	N/A						
NUMAPPARA	3		675	8.8	199,000	3.4	750	9.1	321,000	4.9	5	0.0	N/A	0.62		BLOCK	DAILY CYCLE	2	20
SHINTOYONE	5		1,125	23.8	518,667	5.3	1,300	19.6	618,305	5.4	N/A	0.0	N/A	0.84		5	DAILY CYCLE	6	8
MASEGAWA	2		288													BLOCK	(3)		
OKUYAHAGI PLANT 1	3		343													BLOCK	DAILY CYCLE		
OKUYAHAGI PLANT 2	3		783													BLOCK	DAILY CYCLE		

(1) LEWISTON IS OPERATED TO MEET THE DEMAND OF THE ROBERT MOSES PLANT
(2) TAUM SULK IS OPERATED ONLY WHEN EMERGENCY POWER IS NEEDED
(3) MASEGAWA IS OPERATED TO MEET IRRAGATION NEEDS

FILE PLTDT700.WK1

PROJECT DATA SUMMARY
TABLE 4
MAINTENANCE DATA

APPENDIX A
SHEET 4

NAME	NUMBER OF UNITS	CAPACITY (MW)	PUMP-TURBINE OUTAGE %	AVAILABILITY %	UNIT OVERHAUL PERIOD (YEARS)	UNIT OVERHAUL TIME REQUIRED (DAYS)	UNIT OVERHAUL (MAN-HOURS)	REG. MAINTENANCE PERIOD (MONTHS)	REG. MAINTENANCE TIME REQUIRED (DAYS)	REG. MAINTENANCE (MAN-HOURS)	ANNUAL O&M COST ($1000) 1982	1983	1984	AVE O&M COST (Mil/Kwh) (1) 1982	1983	1984
DOMESTIC PROJECTS																
BATH COUNTY	6	2,592		90												
BEAR SWAMP	2	600	10	90.3	11	119		12	11		622	823	2,417	1.39	20.24	34.29
BLENHEIM GILBOA	4	1,000	8	92.8	10	90	36000	12	10	4000	7,219	6,910	3,530			
CABIN CREEK	2	300		91 to 96							1,046	874	883	8.05	8.05	8.08
CARTERS	4	750	1.4	95.6		N/A			N/A							
CASTAIC	6	1,275				126			N/A		6,449	7,821	10,178			
FAIRFIELD	8	511	10	90				12	14	800	1,348		1,417	3.12		3.45
HELMS	3	1,206		91				12/36	5/35	500/7500						
HORSE MESA	2	366									876	997	1,932	22.41	5.19	31.73
JOCASSEE	4	612		89.6							3,786	2,322	1,467	5.68	2.23	3.55
LEWISTON	12	240	5.49	94.5		75			8	3000	783	1,091				
LUDINGTON	6	1,658	8	92	14	273 (PLANNED)					3,207	2,516	2,105	1.23	0.9	1
MORMON FLAT	2	86									1,856	367	527	66.42	3.89	8.16
MOUNT ELBERT	2	200	32.1	67.9				12	30	12000						
MUDDY RUN	8	800		80		30	240				4,518	5,595	5,651	4.01	5.71	4.58
NORTHFIELD MOUNTAIN	4	846									5,280	5,983	9,611	6.76	6.82	8.99
RACCOON MOUNTAIN	4	1,530		88.4(74.5)		-		24	14		2,774	4,165	4,184	2.29	3.08	2.78
SALINA	6	260									360	1,162	411	4.83	11.19	8.46
SAN LUIS	8	388		73.8	15-20	60	2400									
SENECA	3	422		94							1,286	1,973	2,487	2.15	3.85	3.75
SMITH MOUNTAIN	5	547	4					12	10	1000	1,463	1,363	1,431	3.71	2.6	3.52
TAUM SAUK	2	408	less than 5			120	15000		12		482	543	437	54.99	23.51	27.71
WALLACE	6	321	0.35			48	9600	12		1200	1,739	1,898	2,582	4.97	4.62	6.29
YARDS CREEK	3	330	10	90	10	84	6720	12	10	2000	902	1,710	1,536	2.18	3.58	2.6
FOREIGN PROJECTS																
DINORWIG	6	1,550														
FFESTINIOG	4	360		89	24	182	32000	12	24	700						
TURLOUGH HILL	4	292		88.75					6							
LE TRUEL / LE POUGET	1															
MONTEZIC	4															
BAJINA BASTA	2	348														
MINGHU	4	1,000														
NUMAPPARA	3		6.8	93.20	10	60	28000	12	7	350						
SHINTOYONE	5		9.45	90.55	10	60	28000	12	7	350						
MASEGAWA	2															
OKUYAHAGI PLANT 1	3															
OKUYAHAGI PLANT 2	3															

(1) OPERATION AND MAINTENANCE COST PER KWH BASED ON ANNUAL ENERGY GENERATED

FILE PLTDT400.WK1

PROJECT DATA SUMMARY
TABLE 5
PUMP/TURBINE DATA

APPENDIX A
SHEET 5

NAME	PUMP-TURBINE MANUFACTURER	PUMP TURBINE TYPE	RATED TURBINE NET HEAD (FT)	UNIT TURBINE OUTPUT (MW)	RATED HEAD AS PUMP	RATED PUMP UNIT DISCHARG (CFS)	TURBINE OPER. SPEED (RPM)	OPERATING RANGE/TURB % / %	PUMP GATE POS %	PUMP STARTING POWER IN AIR (MW)	ELEVATION OF PUMP-TURBINE (FT)	PUMP SUBMERGENCE (FT)	TURBINE MODEL TESTS BY	FIELD TESTS
DOMESTIC PROJECTS														
BATH COUNTY	ALLIS-CHALMERS	FRANCIS	1262.0	350.0	1080.0	4500	257	85 to 115	46-65	5 to 7	1975.00	65.00	ALLIS CHALMERS	INDEX
BEAR SWAMP	HITACHI	FRANCIS	720.0	298.0	865.0	4430	225	50 to 80			760.00	60.00	HITACHI	
BLENHEIM GILBOA	HITACHI	FRANCIS	1002.0	250.0	1085.0	2840	257	60 to 120			810.00	50.00	HITACHI	
CABIN CREEK	ALLIS-CHALMERS	FRANCIS	1190.0	160.0	1230.0	840	360	40 to 106	39		9935.00		ALLIS CHALMERS	INDEX
CARTERS	ALLIS-CHALMERS	FRANCIS	345.0	129.0	347.0	4435	150			36 - 6	649.00	21.00	ALLIS-CHALMERS	GIBSON
CASTAIC	HITACHI	FRANCIS	1000.0	239.0	1060.0	1870	257	not 40 to 75			1430.00			
FAIRFIELD	ALLIS-CHALMERS	FRANCIS	167.0	64.8	173/158	4615/4985	150	70 to 100	60	3-5	224.00	30.00	ALLIS-CHALMERS	INDEX
HELMS	HITACHI	FRANCIS	1625.0	350.0	1500.0	2400	360	15 to 100	70				HITACHI	
HORSE MESA	BALDWIN-LIMA-HAMILTON	FRANCIS	246.5	80.0	260.5	3800	150		FIXED		1635.00	18.00	BLH	
JOCASSEE	ALLIS-CHALMERS	FRANCIS	294.0	170.0	294.0	6200	120	65 to 111	65		769.00	12.00	ALLIS-CHALMERS	INDEX
LEWISTON	ALLIS-CHALMERS	FRANCIS	75.0	20.9	85.0	3400	112.5	165 to 180	165 to 180	40	553.50	13.00		GIBSON
LUDINGTON	HITACHI	FRANCIS	320.0	360.0	305/339	1100/9100	112.5		60-70					RES.VOLUME
MORMON FLAT	ALLIS-CHALMERS	FRANCIS	129.0	42.0	130.0	4070	138.5		FIXED		1504.00	9.00	ALLIS CHALMERS	
MOUNT ELBERT (UNIT 1)	ALLIS CHALMERS	FRANCIS	442.0	100.0	405.0	3200	180		100	7	9140.00	50.00		ALLEN
(UNIT 2)	TOSHIBA	FRANCIS	442.0	100.0	405.0	3200	180		76	7	9140.00	50.00		
MUDDY RUN	BALDWIN-LIMA-HAMILTON	FRANCIS	353.0	103.0	427.0	2610	180	40 to 100	55		80.00	20.00		INDEX
NORTHFIELD MOUNTAIN	BALDWIN-LIMA-HAMILTON	FRANCIS	745.0	260.0	740.0	3600	257				72.00	106.00		
RACCOON MOUNTAIN	ALLIS-CHALMERS	FRANCIS	1020.0	391.0	1000.0	3850	300	9.7			505.00	126.50	ALLIS CHALMERS	INDEX
SALINA	ALLIS-CHALMERS	FRANCIS	225.0	44.7	245.0	2100	171.4							
SAN LUIS	HITACHI	FRANCIS	197.0	52.2	290.0	2030	150			0.5	202.00	15.00	HITACHI	ALLEN
SENECA	NEWPORT NEWS	FRANCIS	646.0	162.0	700.0	3200	225	63 to 100	BEST EFF		1188.00		NEWPORT NEWS	VENTURI
SMITH MOUNTAIN (UNIT 3)	ALLIS-CHALMERS	FRANCIS	170.0	105.0	188.0	7080	90	40 to 90	40		597.00	3-16		
(UNITS 1 & 5)	ALLIS CHALMERS	FRANCIS	180.0	65.0	205.0	3900	106	49 to 90	65		597.00	3-16	ALLIS CHALMERS	
TAUM SAUK	ALLIS-CHALMERS	FRANCIS	790.0	220.0	764.0	2650	200		42-47	8	703.00	30.00		INDEX
WALLACE	ALLIS-CHALMERS	FRANCIS	89.0	52.2	98.0	6500	85.7		65	30-35	332.80	7.20		INDEX
YARDS CREEK	BALDWIN-LIMA-HAMILTON	FRANCIS	656.0	113.0	732.0	2145	240	80 to 115	64	7	770.00	25.00	BLH	
FOREIGN PROJECTS														
DINORWIG	BOVING	FRANCIS	1758.0	317.0	1787.0	1766	500	28 to 104			103.68	198.11	BOVING	PLANNED
FFESTINIOG	ENGLISH ELECTRIC	FRANCIS W/ PUMP	925.0	94.0	1000.0	745	429	65 to 100	N/A	N/A	548.00	49.00	ENGLISH ELECTRIC	
TURLOUGH HILL	KMW	FRANCIS	941.0	73.0	943.0	781	500				1213.97	81.33	KMW	RES. VOLUME
LE TRUEL	NEYRPIC	FRANCIS	1443.0	38.0	1427.0	244	750	10 to 100	FIXED				NERYPIC	THERMODYNAMIC
MONTEZIC	NEYRPIC	FRANCIS	1367.0	228.0	1400.0	1512	429	44 to 100	55-60	5	768.50	171.42		THERMODYNAMIC
BAJINA BASTA	TOSHIBA	FRANCIS	1819.0	294.0	2038/1744	1296/1794	429		70-90			177.12	TOSHIBA	INDEX
MINGHU	HITACHI	FRANCIS	1016.0	250.0	1070.0	2896	300					125.30		
NUMAPPARA	HITACHI	FRANCIS	1568.0	230.0	1503/1732	1766/989	375	60 to 100	80-86	20-30	2214.68	151.30	HITAHCI	VENTURI
SHINTOYONE	TOSHIBA	FRANCIS	666.0	230.0	590/804	4341/2910	257,250,214/257	60 to 100	BEST EFF	20	636.51	46.00	TOSHIBA	VENTURI
MASEGAWA	HITACHI	DARIAZ	327.0	149.0	360/180	4719/5916	180				869.47			
OKUYAHAGI PLANT 1	TOSHIBA	FRANCIS	529.0	105.0	598.0	2402	300		BEST EFF					
OKUYAHAGI PLANT 2	HITACHI	FRANCIS	1326.0	267.0	1463.0	1766	360				705.38			

PROJECT DATA SUMMARY
TABLE 5 (cont.)
PUMP/TURBINE DATA

NAME	RUNNER DESCRIPTION	RUNNER DIA. (FT)	RUNNER MATERIAL	DISTRIBUTOR DESCRIPTION	NO. OF SERVOMOTORS	ADJUSTABLE GUIDE VANES (Y/N)	WICKET GATE MATERIAL	SHAFT SEAL DESCRIPTION	THRUST BEARING LOCATION	THRUST BEARING SUPPORT	NUMBER OF GUIDE BEARINGS	RUNNER REMOVAL
DOMESTIC PROJECTS												
BATH COUNTY		20.83	13-4SS		2	Y	SS	CARBON RING	BELOW ROTOR	HEAD COVER	3	ABOVE
BEAR SWAMP		19.16	STEEL	RUBBER	2	Y	CAST STL	CARBON RING	BELOW ROTOR	BRACKET	3	ABOVE
BLENHEIM GILBOA		19.90		BRONZE	2	Y	CAST STL	MECHANICAL	BELOW ROTOR	BRACKET	3	ABOVE
CABIN CREEK			SS(1)		2	Y	CAST STL	PACKING BOX	ABOVE ROTOR	BRACKET	3	ABOVE
CARTERS	SPLIT	20.66	STEEL	RUBBER	2	N	CAST STL	PACKING BOX	ABOVE ROTOR	BRACKET	2	ABOVE
CASTAIC		19.25	SS	BRASS	2	Y	CAST STL	MECHANICAL	BELOW ROTOR	BRACKET	2	ABOVE
FAIRFIELD			STEEL	RUBBER	INDIVIDUAL	Y	CAST STL	MECHANICAL(2)	BELOW ROTOR	BRACKET	2	ABOVE
HELMS		17.17	SS		2	Y	CAST STL	CARBON/RESIN	BELOW ROTOR	BRACKET	3	ABOVE
HORSE MESA			STEEL		2	Y	CAST STL		BELOW ROTOR	BRACKET	3	ABOVE
JOCASSEE		24.00	STEEL	RUBBER	2	Y	CAST STL	PACKING BOX	BELOW ROTOR	BRACKET	2	ABOVE
LEWISTON	SPLIT	17.10	CAST/PL STL		2	Y	CAST STL	PACKING BOX	BELOW ROTOR	BRACKET	2	ABOVE
LUDINGTON	SPLIT			RUBBER	2	Y	CAST STL	PHENOLIC RING	BELOW ROTOR	BRACKET	3	ABOVE
MORMON FLAT			STEEL		2	Y	CAST STL		BELOW ROTOR	BRACKET	2	ABOVE
MOUNT ELBERT (UNIT 1)		18.83	SS	BRONZE	2	Y	SS	PACKING BOX	BELOW ROTOR	BRACKET	2	ABOVE
(UNIT 2)			SS	RUBBER	2	Y	SS	MECHANICAL	BELOW ROTOR	BRACKET	2	ABOVE
MUDDY RUN		17.91	CAST STL		2	Y	CAST STL	PACKING BOX	BELOW ROTOR	BRACKET	2	ABOVE
NORTHFIELD MOUNTAIN					2	Y	CAST STL(3)	PACKING BOX	BELOW ROTOR	BRACKET	3	ABOVE
RACCOON MOUNTAIN		16.58	SS	BRASS	2	Y	CAST SS	PACKING BOX	BELOW ROTOR	BRACKET	2	ABOVE
SALINA					2	Y	CAST STL		BELOW ROTOR	BRACKET	2	ABOVE
SAN LUIS		17.50	SS			N	CAST STL	CARBON RING	ABOVE ROTOR	BRACKET	3	ABOVE
SENECA	SPLIT	18.67	STEEL	RUBBER	2	Y	CAST STL	PACKING BOX	BELOW ROTOR	BRACKET	2	ABOVE
SMITH MOUNTAIN (UNIT 3)	SPLIT	19.80	STEEL		2	Y	FAB STL	PACKING BOX	BELOW ROTOR	BRACKET	2	ABOVE
(UNITS 1 & 5)	SPLIT	16.00	STEEL		2	Y	FAB STL (4)	PACKING BOX	BELOW ROTOR	BRACKET	3	ABOVE
TAUM SAUK	SPLIT	21.50	STEEL		2	Y	CAST STL	PACKING BOX	BELOW ROTOR	BRACKET	2	ABOVE
WALLACE	SPLIT	26.67	STEEL		INDIVIDUAL	N	CAST STL	PACKING BOX	ABOVE ROTOR	BRACKET	2	ABOVE
YARDS CREEK		18.50	SS(1)		2	Y	SS (4)	PACKING BOX	ABOVE ROTOR	BRACKET	3	ABOVE
FOREIGN PROJECTS												
DINORWIG		12.45	SS	NYLON	2	Y	CAST STEEL	MECHANICAL	ABOVE ROTOR	BRACKET	3	ABOVE
FFESTINIOG		8.42	SS	RUBBER	2	Y	CAST STEEL	CARBEN RING	ABOVE ROTOR	BRACKET	6	ABOVE
TURLOUGH HILL		5.12	SS	NYLON	2	Y	SS	CARBON RING	ABOVE ROTOR	BRACKET	3	ABOVE
LE TRUEL		5.49	SS		2 PER STAGE	Y	SS	LABYRINTH	BELOW P/T	FLOOR	4	BELOW
MONTEZIC		13.16	SS		INDIVIDUAL	Y	SS	CARBON RING	BELOW ROTOR	HEAD COVER	3	BELOW
BAJINA BASTA		15.74	SS		2	Y	CAST STEEL	CARBON RING	BELOW ROTOR	BRACKET		ABOVE
MINGHU		16.70			2	Y	CAST STEEL	PACKING BOX	BELOW ROTOR	BRACKET	3	ABOVE
NUMAPPARA	SPLIT	16.40	STEEL	BRONZE	2	Y	CAST STEEL	MECHANICAL	BELOW ROTOR	BRACKET	3	ABOVE
SHINTOYONE	SPLIT		STEEL	BRONZE	2	Y	CAST STEEL	MECHANICAL	BELOW ROTOR	BRACKET	3	ABOVE
MASEGAWA		16.40	SS	RUBBER		Y	CAST STEEL	MECHANICAL	BELOW ROTOR	BRACKET	3	ABOVE
OKUYAHAGI PLANT 1		13.12			2	Y	CAST STEEL		BELOW ROTOR	BRACKET	3	ABOVE
OKUYAHAGI PLANT 2		16.08			2	Y	CAST STEEL		BELOW ROTOR	BRACKET	3	ABOVE

(1) CABIN CREEK, YARDS CREEK ORIGIONALLY MILD STEEL RUNNERS
(2) FAIRFIELD CHANGED TO MECHANICAL SEALS
(3) NORTHFIELD #3 WICKET GATES GHANGED TO 17-4 SS
(4) SMITH MOUNTAIN AND YARDS CREEK ORIGIONALLY MILD STEEL WICKET GATES

FILE PLTDTB00.WK1

PROJECT DATA SUMMARY
TABLE 6
GENERATOR-MOTOR DATA

APPENDIX A
SHEET 7

NAME	GEN.-MOTOR MANUFACTURER	GENERATOR OUTPUT (MVA)	GENERATOR POWER FACTOR	GENERATING VOLTAGE (KV)	GENERATING COOLING	GENERATOR ROTOR WEIGHT (TON)	GEN.-MOTOR EXCITATION TYPE	GEN.-MOTOR NO. OF POLES	GEN.-MOTOR FIRE PROTECTION TYPE	MOTOR OUTPUT (MW)
DOMESTIC PROJECTS										
BATH COUNTY	SEIMENS ALLIS	389.00	0.90	20.50	AIR TO WATER COOLERS	716	STATIC	28	CO2	410.00
BEAR SWAMP	TOSHIBA	333.00	0.90	13.80	AIR TO WATER COOLERS	583	ROTATING AMPLIFER	32	CO2	309.00
BLENHEIM GILBOA	HITACHI	278.00	0.90	17.00	AIR TO WATER COOLERS	497	D.C. GENERATOR	28	CO2	272.00
CABIN CREEK	GENERAL ELECTRIC	167.00	0.90	13.80	AIR TO WATER COOLERS			20		136.00
CARTERS	GENERAL ELECTRIC	132.00	0.95	13.80	AIR TO WATER COOLERS	285	ROTATING. AMPLIDYNE	48	CO2	123.00
CASTAIC	ASEA	250.00	0.85	18.00	AIR TO WATER COOLERS	550	STATIC	28		231.00
FAIRFIELD	ALLIS CHALMERS	71.00	0.90	13.80	AIR TO WATER COOLERS	175	STATIC	48	CO2	77.00
HELMS	WESTINGHOUSE	390.00	0.90	18.00	AIR TO WATER COOLERS	520	STATIC	20	CO2	320.00
HORSE MESA	WESTINGHOUSE	96.50	0.90	13.80	AIR TO WATER COOLERS	220	STATIC	48		84.00
JOCASSEE	WESTINGHOUSE	170.00	0.90	14.40	AIR TO WATER COOLERS	400	STATIC	60	CO2	174.00
LEWISTON	ALLIS-CHALMERS	25.00	0.80	13.80	AIR TO WATER COOLERS	110	DC GENERATOR	64	CO2	28.00
LUDINGTON	HITACHI	325.00	0.85	20.00	AIR TO WATER COOLERS		ROTATING. AMPLIDYNE	64		276.00
MORMON FLAT	ALLIS-CHALMERS	47.00	0.90	13.80	AIR TO WATER COOLERS	167	STATIC	52	CO2	45.50
MOUNT ELBERT (UNIT 1)	WESTINGHOUSE	105.30	0.95	11.50	AIR TO WATER COOLERS	315	STATIC	40	CO2	127.00
(UNIT 2)	HITACHI	105.30	0.95	11.50	AIR TO WATER COOLERS	260	STATIC	40	CO2	127.00
MUDDY RUN	WESTINGHOUSE	111.00	0.90	13.80	AIR TO WATER COOLERS	80	ROTATING	40	CO2	100.00
NORTHFIELD MOUNTAIN	GENERAL ELECTRIC	235.00	0.90	13.80	AIR TO WATER COOLERS		ROTATING. AMPLIDYNE	28		217.00
RACCOON MOUNTAIN	SEIMENS-ALLIS	425.00	0.90	23.00	WATER COOL STATOR & ROTOR	440	STATIC	24	CO2	345.00
SALINA	WESTINGHOUSE	48.00	0.90	13.80	AIR TO WATER COOLERS			42		48.00
SAN LUIS	GENERAL ELECTRIC	53.00	1.00	13.80	AIR TO WATER COOLERS	128	ROTATING. AMPLIDYNE	2-46/60; 6-48/60	CO2	53.3-47/25
SENECA	WESTINGHOUSE	220.00	0.90	13.80	AIR TO WATER COOLERS	221		32	HALON	195.00
SMITH MOUNTAIN (UNIT 3)	SIEMENS-ALLIS	141.18	0.95	13.80	AIR TO WATER COOLERS	414	STATIC	80	CO2	127.60
(UNITS 1 & 5)	ALLIS CHALMERS	69.50	0.95	18.80	AIR TO WATER COOLERS	297	CD GENERATOR	68	CO2	75.70
TAUM SAUK	GENERAL ELECTRIC	204.00	1.00	13.80	AIR TO WATER COOLERS	138		36	CO2	179.00
WALLACE	GENERAL ELECTRIC	52.20	0.90	14.40	AIR TO WATER COOLERS	250	STATIC	84	CO2	61.90
YARDS CREEK	GENERAL ELECTRIC	125.00	0.90	14.40	AIR TO WATER COOLERS	327	ROTATING. AMPLIDYNE	30	CO2	140.00
FOREIGN PROJECTS										
DINORWIG	GEC	313.50	0.95	18.00	AIR TO WATER COOLERS		STATIC	12		313.50
FFESTINIOG	AEI	95.00	0.95	16.00	AIR TO WATER COOLERS	600	ROTATING AMPLIDINE	14	NONE	78.90
TURLOUGH HILL	SIEMENS	87.50	0.85	10.50	AIR TO WATER COOLERS			12		
LE TRUEL	CEM	41.50	0.90	5.65	AIR TO WATER COOLERS		STATIC	8		42.00
MONTEZIC		250.00	0.91	18.00	AIR TO WATER COOLERS		STATIC	14	CO2	234.00
BAJINA BASTA	TOSHIBA	315.00	0.95	11.00	AIR TO WATER COOLERS			14		
MINGHU	MITSUBISHI	280.00	0.90	16.50	AIR TO WATER COOLERS	440	STATIC	20	CO2	260.00
NUMAPARRA	HITACHI	250.00	0.95	16.50	AIR TO WATER COOLERS	488	STATIC	16	N/A	250.00
SHINTOYONE	TOSHIBA	250.00	0.95	16.50	AIR TO WATER COOLERS	550	STATIC	28/24	CO2	260.00
MASEGAWA	HITACHI	160.00	0.90	13.80	AIR TO WATER COOLERS			40		160.00
OKUYAHAGI PLANT 1					AIR TO WATER COOLERS			24		
OKUYAHAGI PLANT 2	HITACHI	290.00	0.90	18.00	AIR TO WATER COOLERS			20		283.00

PROJECT DATA SUMMARY
TABLE 7
POWER AND CONTROL

NAME	STARTING METHOD	SWICTHYARD TYPE	POWER TRANS. NUMBER	POWER TRANS. TYPE	POWER TRANS. RATING (MVA)	TRANSFORMER VOLTAGES	CONTROLS TYPE	CONTROLS COMPUTER
DOMESTIC PROJECTS								
BATH COUNTY	SYNCH OR FREQ. CONVERTER	SF6 RING BUS	9	SINGLE PHASE	.69/92.5/1.15	500KV-20.5 KV	HARDWIRE RELAYS	NO
BEAR SWAMP	PONY MOTOR	RING BUS	2	3-PHASE	330.00	230/115/13.8 KV	HARDWIRE RELAYS	REMOTE
BLENHEIM GILBOA	PONY MOTOR	BREAKER & HALF	4	3-PHASE FOA	285.00	345KV/16.2 KV	HARDWIRE RELAYS	LOCAL/REMOTE
CABIN CREEK	PONY MOTOR		1			230/115/11.5 KV		
CARTERS	REDUCED FREQUENCY	DBL BUS/DBL BKR	2	3-PHASE FOA	176.90	230/13.2 KV	SEMI-AUTO RELAY LOGIC	NO
CASTAIC	BACK-TO-BACK SYNCH.	DBL BUS/DBL BKR	6	3-PHASE FOA	290.00	230KV/18 KV		
FAIRFIELD	REDICED-VOLTAGE, TRANSFORMER TAP			3-PHASE FOA	171.00	230KV/13.8KV	HARDWIRE RELAYS	NO
HELMS	PONY MOTOR	SINGLE BUS, TIE BKRS	9	3-PHASE FOA	150.00	18KV/320KV	HARDWIRE RELAYS	
HORSE MESA	PONY MOTOR		1			13.8KV/115 KV	HARDWIRE RELAYS	NO
JOCASSEE	SEMI-SYN. (3 UNITS),RED VOLT. (1 UNIT)	BREAKER & HALF	4	3-PHASE FOA	183.00	14.4-230KV	HARDWIRE RELAYS	LOCAL/REMOTE
LEWISTON	FULL-VOLTAGE ACROSS-THE-LINE	AIR-BREAKER & HALF	4	3-PHASE FOA	100.00	240KV/13.2 KV	HARDWIRE RELAYS	REMOTE
LUDINGTON	4 UNITS BACK-TO-BACK, 2 UNITS PONY MOTOR	BREAKER & HALF	3	1-PHASE FOA	3X257	19.5-345KV	HARDWIRE RELAYS	REMOTE
MORMON FLAT	REDUCED VOLTAGE		1	3-PHASE FOA		13.8KV/115 KV	HARDWIRE RELAYS	NO
MOUNT ELBERT	SYNCHRONOUS, STATIC AC FREQ CONVERTER	SURFACE	2	3-PHASE	144.00	230/11.5 KV	HARDWIRE RELAYS	NO
MUDDY RUN	REDUCED VOLTAGE		4	3-PHASE	250.00	230/13.8 KV		NO
NORTHFIELD MOUNTAIN	PONY MOTOR		2	3-PHASE FOW	500.00	13.8-345KV		
RACCOON MOUNTAIN	SYNCHRONOUS, STATIC AC FREQ CONVERTER	BREAKER & HALF	4	3-PHASE FOW	415.00	23.0-161KV	HARDWIRE RELAYS	NO
SALINA	FULL VOLTAGE ACROSS-THE-LINE						HARDWIRE RELAYS	
SAN LUIS	FULL-VOLTAGE ACROSS-THE-LINE	SPT MAIN & TRANSFORMER	4	3-PHASE OA/FA/FOA	105.00	230/13.8 KV	HARDWIRE RELAYS	YES
SENECA	BACK-TO-BACK SYNCH.		2			230/13.8 KV		
SMITH MOUNTAIN	REDUCED VOLTAGE	BREAKER & HALF	4	3-PHASE	150.00	13.8-138KV	HARDWIRE RELAYS	LOCAL/REMOTE
TAUM SAUK	PONY MOTOR	REMOTE SW YD	2	3-PHASE FOA	230.00	13.5-138KV	HARDWIRE RELAYS	
WALLACE	LINE W/ POSSIBLE FUTURE SYNCHRONOUS START	DBL BUS/DBL BKR	'2	3-PHASE FOA		14.4-230KV	HARDWIRE RELAYS	NO
YARDS CREEK	REDUCED-VOLTAGE, STARTING REACTORS	MAIN BUS	3	3-PHASE FOA	144.00	14.4/230 KV	HARDWIRE RELAYS	NO
FOREIGN PROJECTS								
DINORWIG	SYNCHRONOUS, STATIC AC FREQ CONVERTER					5.65-225KV		
FFESTINIOG	DRIVEN BY TURBINE	SNGL BUS/SNGL BKR	'2	3-PHASE FOA	180.00	16/275KV	HARDWIRE RELAYS	NO
TURLOCH HILL	PONY MOTOR					10.5-220KV		
LE TRUEL / LE POUGET	BACK TO BACK	SINGLE BUS/SNGL BKR	1	3-PHASE FOA	41.50	5.65-225KV		
MONTEZIC	SYNCHRONOUS, STATIC AC FRQ CONVERTER	SINGLE BUS/SNGL BKR	4	3-PHASE	250.00	18.0-405KV	COMPUTERIZED	REMOTE
BAJINA BASTA	BACK-TO-BACK						HARDWIRE RELAYS	
MINGHU	PONY MOTOR & BACK-TO-BACK	DOUBLE BUS/SNGL BKR	4	3-PHASE FOW	280.00	16.5-345KV		
NUMAPARRA	PONY MOTOR & BACK TO BACK	SNGL BUS/SNGL BKR	3	3-PHASE FOW	255.00	16.5-275KV	HARDWIRE RELAYS	REMOTE
SHINTOYONE	PONY MOTOR & BACK TO BACK	SNGL BUS/SNGL BKR	5	3-PHASE FOW	265.00	16.5-275KV	SEQUENCER	REMOTE
MASEGAWA							HARDWIRE RELAYS	
OKUYAHAGI PLANT 1								LOCAL/REMOTE
OKUYAHAGI PLANT 2								LOCAL/REMOTE

PROJECT DATA SUMMARY
TABLE 8
UPPER DAM AND RESERVOIR DATA

NAME	SURFACE AREA AT TOP WATER LEVEL (AC)	USABLE VOLUME (AC FT)	UPPER DAM TYPE	DAM HEIGHT (FT)	DAM CREST LENGTH (FT)	UPPER DAM VOLUME (CU YD)	MAXIMUM WATER LEVEL (FT)	MINIMUM WATER LEVEL (FT)	POWER POOL CHANGE (FT)	RESERVOIR TYPE	RESERVOIR DRAINAGE AREA (SQ MILES)	SPILLWAY TYPE	SPILLWAY DESIGN FLOOD PEAK DISCHARGE (CU FT/S)	INTAKE TYPE	NO.
DOMESTIC PROJECTS															
BATH COUNTY	265	22,500	ROCKFILL W/ CORE	460	2,200	17,000,000	3,320.0	3,215.0	105.0	ON STREAM	2.4	FUSE PLUG	18,002	POWER	3
BEAR SWAMP	118	8,870	ROCKFILL W/ CORE	155 *		123,713	1,600.0	1,550.0	50.0	ARTIFICIAL	1249.7	OVERFLOW WEIR	6,701	GLORY HOLE	1
BLENHEIM GILBOA	360	15,000	EARTH DIKE W/CORE	162	11,900	5,875,471	2,003.0	1,955.0	48.0	ARTIFICIAL	0.6	OVERFLOW	3,200	UNGATE CIRC. WEIR	
CABIN CREEK	25	1,457	ROCKFILL W/ CONC. FACE	210	1,458	1,194,000	11,195.0	11,105.0	90.0	ARTIFICIAL	1.0	WEIR	50		1
CARTERS	3,880	134,900	ROCKFILL W/ CORE	445	2,053	13,500,000	1,099.0	1,022.0	77.0	ON STREAM	376.0	GATED-CONC. GRAVITY	199,200	POWER	4
CASTAIC	1,357	179,000	ROCKFILL	386	1,080	6,952,000	2,578.0			ARTIFICIAL	292.6	BROAD CRESTED WEIR	N/A	TUNNEL	1
FAIRFIELD	6,800	29,000	EARTH EMBANKMENT W/CORE	180	10,000	9,000,000	425.0	420.5	4.5	ON STREAM	15.0	NONE	N/A	CONCRETE STRUCTURE	4
HELMS	1,621	119,200	EARTH W/ CONC. FACE	304	862	123,300	8,184.0	8,020.0	164.0	ON STREAM	40.0	CHUTE	12,000	TUNNEL	
HORSE MESA	2,660		CONC. THIN ARCH	305	660	162,000	1,914.0	1,896.0	18.0	ON STREAM		OVRFL(2);CONC. LND TNL	150,000		
JOCASSEE	7,565	215,700	ROCKFILL W/ CORE	385	1,750	11,379,600	1,110.0	1,080.0	30.0		1.5	CONCRETE CHUTE		SUBM. DROP INLET	2
LEWISTON	1,900	60,000	ROCKFILL W/ CORE	35	334,320	99,037,000	655.0	620.0	35.0	ARTIFICIAL	3.0	NONE		HORIZONTAL	12
LUDINGTON		54,000	EARTHFILL W/ASPHALT FACE			132,777,000	942.0	875.0	67.0			NONE			
MORMON FLAT	950		CONC. THIN ARCH	224	380	59,900	1,660.5	1,645.5	15.0			CONC. LINED CHANNEL	150,000		
MOUNT ELBERT	270	7,126	EARTHFILL W/ PVC LINER	90	1,500	845,700	9,647.0	9,590.0	57.0	ARTIFICIAL		MORNING GLORY		SUBM. DROP	2
MUDDY RUN	960	33,200	EARTH & ROCKFILL	250	4,800	5,185,600	520.0	470.0	50.0	ARTIFICIAL	9.2	CONC., NON-GATED	13,000	CONC. STRUC.	
NORTHFIELD MOUNTAIN			ROCKFILL W/ CORE	160			1,004.5	920.0	84.5	ARTIFICIAL					
RACCOON MOUNTAIN	528	36,340	EARTH & ROCKFILL	230	8,500	10,224,154	1,672.0	1,530.0	142.0	ARTIFICIAL	1.4	NONE	N/A	CONC TOWER	
SALINA	785		EARTHFILL	200	2,300	3,700,000									
SAN LUIS	12,729	2,000,000	EARTHFILL	385	18,600	75,000,000	543.8	326.0	217.8	OFF STREAM	85.0	GLORY HOLE	1,030	TOWER	4
SENECA	110	5,755	ROLLED FILL-SANDSTONE	115	7,800	14,893,000	2,073.3	2,003.3	70.0	ARTIFICIAL	NONE	FUSE PLUG		SUBM. BELL MOUTH	
SMITH MOUNTAIN	21,500	150,000	CONC. ARCH DAM	235	815	175,000	795.0	793.2	1.8	ON STREAM	1020.0	OVERFLOW WITH CHUTE	50,000	IN DAM	
TAUM SAUK	55	4,350	ROCKFILL DAM			3,750,000	1,597.0	1,505.0	92.0						
WALLACE	18,000	150,000	EARTHFILL & CONCRETE			825,644	435.0	428.0	7.0	ON STREAM	1830.0	5 RADIAL GATES	35,000		
YARDS CREEK	162	4,650	ROCKFILL W/ CORE	70	9,600		1,555.0	1,506.0	49.0	ARTIFICIAL		N/A	N/A	BELL MOUTH CON STR	1
FOREIGN PROJECTS															
DINORWIG	66	5,189	EARTHFILL W/ASPHALT FAC	1	1,968	1,794,000	2,076.0	1,968.0	108.0	ARTIFICIAL	MINIMAL	BELLMOUTH	1,828	TUNNEL	1
FFESTINIOG	29	1,012	CONC. GRAV. BUTTRESS	121	801	2,616,000	1,648.3	1,583.0	65.3	ARTIFICIAL	0.3	OVERFALL	2,500	CONCRETE STRUCTURE	1
TURLOUGH HILL	36	1,705	ROCKFILL	112	4,740	1,705,565	2,274.0	2,209.0	65.0	ARTIFICIAL	MINIMAL	NONE	N/A	TOWER	1
LE TRUEL															
MONTEZIC	61	24,321	ROCKFILL W/ CORE	187	2,690	2,243,460	2,306.4	2,231.0	75.4	ARTIFICIAL	6.5	CONCRETE WEIR	1,400	HORIZONTAL	2
BAJINA BASTA															
MINGHU							2,455.0	2,385.2	69.8	NATURAL LAKE					
NUMAPARRA	44	3,421	EARTH W/ ASPHALT FACE	125	5,420	1,648,048	4,061.7	3,930.4	131.3	ARTIFICAL	0.3	HORIZONTAL TUNNEL	664	CONC. STRUCT.	
SHINTOYONE	351	32,753	CONCRETE ARCH	382	1,020	69,975,358	1,555.0	1,427.0	128.0	ON STREAM	53.0	GATED OVERFLOW	63,566	CONC. STRUCT.	
MASEGAWA															
OKUYAHAGI PLANT 1															
OKUYAHAGI PLANT 2															

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APPENDIX A
SHEET 10

PROJECT DATA SUMMARY
TABLE 9
LOWER DAM AND RESERVOIR DATA

NAME	SURFACE AREA AT TOP WATER LEVEL (AC)	USEABLE VOLUME (AC FT)	LOWER DAM TYPE	DAM HEIGHT (FT)	DAM CREST LENGTH (FT)	LOWER DAM VOLUME (CY)	MAMIMUN WATER LEVEL (FT)	MINIMUM WATER LEVEL (FT)	POOL EL. CHANGE (FT)	RESERVOIR TYPE	RESERVOIR DRAINAGE AREA (SQ MILES)	SPILLWAY TYPE	SPILLWAY DESIGN FLOOD PEAK DISCHARG (CU FT/S)
DOMESTIC PROJECTS													
BATH COUNTY	555	22,500	EARTH & ROCKFILL	135	2,400	3,600,000	2,118.0	2,058.0	60.0	ON STREAM	73.4	RADIAL GATE	60,000
BEAR SWAMP	152	4,900	EARTH & ROCKFILL	130	900	567,000	130.0	40.0	90.0	ON STREAM		RADIAL GATE	77,000
BLENHEIM GILBOA	420	12,700	EARTH & ROCKFILL	100	1,800	26,373,160	900.0	860.0	40.0	ON STREAM	350.0	SIDE CHUTE SPILLWAY	150,000
CABIN CREEK	52	1,905	EARTH & ROCKFILL	95	1,150	1,043,000	10,012.5	9,960.0	52.5	ON STREAM		TUNNEL	1,500
CARTERS	1,030	17,210	ROCKFILL DYKE	65	3,349	766,000	698.0	662.5	35.5	ON STREAM	530.0	TAINTER GATE	197,800
CASTAIC	493	33,000	ARTIFICIAL	170	2,000	5,903,000			65.0	ON STREAM	76.0	BROAD CRESTED WEIR	
FAIRFIELD	4,400	29,000	CONCRETE GRAVITY	37	200		266.0	256.0	10.0	ON STREAM	4790.0	GATED WEIR	
HELMS	1,009	89,100	EXISTING	290	3,330	128,500	6,550.0	6,440.0	110.0	ON STREAM	174.0	RADIAL GATE	30,000
HORSE MESA	950		CONC. THIN ARCH	224	380	59,900	1,660.5	1,655.0	5.5	ON RIVER	N/A	CON. LINED CHANNEL	150,000
JOCASSEE							800.0	797.0	3.0	ON STREAM	5828.0		
LEWISTON	1,900								17.0	ARTIFICIAL	3.0		N/A
LUDINGTON													
MORMON FLAT	1,260		CONC. THIN ARCH	207	1,260	120,500	1,529.0	1,522.0	7.0	ON RIVER	N/A	CONC.WEIR	140,000
MOUNT ELBERT	3,000	68,000	EARTHFILL	55	3,140	624,000	9,200.0	9,168.0	32.0	ON STREAM	N/A	MORNING GLORY	1,400
MUDDY RUN	8,960	81,000	CONC GRAVITY	102		666,720	109.0	109.0	0.0	ON STREAM	27000.0		1,170,000
NORTHFIELD MOUNTAIN							185.0	176.0	9.0	ARTIFICIAL			
RACCOON MOUNTAIN	528	36,340	CONCRETE	N/A	N/A	N/A	633.0	633.0	0.0	ON STREAM	N/A	N/A	N/A
SALINA													
SAN LUIS										OFF STREAM			
SENECA	20,992	4,650	EARTHFILL							ON STREAM	2180.0		
SMITH MOUNTAIN	3,400	35,000	CONC. GRAVITY	94	980	100,000	613.0	600.0	13.0	ON STREAM	1493.0	RADIAL GATE	162,000
TAUM SAUK	395	4,460				22,000	750.0	734.0	16.0		75.0	OGEE WEIR	70,000
WALLACE	15,330	27,600	CONC. GRAVITY	117	870		340.0	338.2	1.8	ON STREAM	2910.0		480,000
YARDS CREEK	305	4,650	EARTHEN	55	3,500	366,610	818.5	795.0	23.5	ON STREAM	4.5	CONCRETE; OGEE	11,000
FOREIGN PROJECTS													
DINORWIG		5,189	ROCKFILL				616.6	597.0	19.7	NATURAL,RAISED		GATED	4,587
FFESTINIOG	121	1,705	CONC. GRAV.	49	1,801		616.6	597.0	19.6	ARTIFICAL	3.7	OVERFALL	4,000
TURLOUGH HILL	52	1,705	NONE NATURAL				1327.8	1,295.2	32.6	NATURAL	0.5	NATURAL	
LE TRUEL													
MONTEZIC	642	24,321	THIN ARCH	199	892	89,700	969.5	918.6	50.9	ON STREAM	3284.0	BROAD CREST WEIR	95,350
BAJINA BASTA				13			348.5	301.8	46.7				
MINGHU			CONCRETE GRAVITY	189	556		1,471.5	1,404.2	67.3	ON STREAM		GATED OVERFLOW	
NUMAPARRA	241	16,944	ROCKFILL ASPHALT FACE	248	1,095	2,572,755	2,470.5	2,365.5	105.0	ON STREAM	20.0	OPEN CHUTE	29,664
SHINTOYONE	1,769	166,555	CONCRETE GRAVITY	510	963	427,534,336	853.0	722.0	131.0	ON STREAM	1603.0	GATED OVERFLOW	271,922
MASEGAWA													
OKUYAHAGI PLANT 1													
OKUYAHAGI PLANT 2													

PROJECT DATA SUMMARY
TABLE 10
WATEATER CONVEYANCE SYSTEM

NAME	LOW PRESSURE TUNNELS NO.	LOW PRESSURE TUNNELS MAX. WATER VELOCITY (FT/S)	LOW PRESSURE TUNNELS LENGTH (FT)	SHAFT NO.	SHAFT MAX. WATER VEL (FT/S)	SHAFT LENGTH (FT)	HIGH PRESSURE TUNNEL NO.	HIGH PRESSURE TUNNEL MAX. WATER VELOCITY (FT/S)	HIGH PRESSURE TUNNEL LENGTH (FT)	UPSTREAM SURGE TANKS DETAILS	PENSTOCK NUMBER	PENSTOCK MAX. VELOCITY (FT/S)	PENSTOCK LENGTH (FT)
DOMESTIC PROJECTS													
BATH COUNTY	3	16.9	7,500	3	16.0	990	3	16.0	8,400	3(44FT X 330FT)	6	21.2-76.2	897 - 1257
BEAR SWAMP	1			1	34.0	740	1	12.8	317	NONE	2	5.5	350
BLENHEIM GILBOA	NONE	N/A	N/A	1	21.0	1,055	1	18.5	1,079	NONE	4		1,960
CABIN CREEK				1	60.0	1,020	1	60.0	312	NONE	1	60.0	1,563
CARTERS	NONE	N/A	N/A	NONE	N/A	N/A	NONE	N/A	N/A	NONE	4	21.2	838
CASTAIC	1	26	38,016	NONE	N/A	N/A	NONE	N/A	N/A	1(120FT X 400FT)	6		2,400
FAIRFIELD	NONE	N/A	N/A	NONE	N/A	N/A	NONE	N/A	N/A	NONE	4	22.6	800
HELMS	1		4,000				1						4,400
HORSE MESA	NONE	N/A	N/A	NONE	N/A	N/A	NONE	N/A	N/A	NONE	1	29.6	
JOCASSEE	1	21.0		1		853					4	21.0	387
LEWISTON	NONE	N/A	N/A	NONE	N/A	N/A	NONE	N/A	N/A	NONE	12	10.0	180
LUDINGTON													
MORMON FLAT	NONE	N/A	N/A	NONE	N/A	N/A	NONE	N/A	N/A	NONE	1	21.2	
MOUNT ELBERT	NONE	N/A	N/A	NONE	N/A	N/A	NONE	N/A	N/A	2(58078 SQ FT)	2	10.0	3,000
MUDDY RUN				4	22.0	350					8	28.5	500
NORTHFIELD MOUNTAIN													
RACCOON MOUNTAIN	NONE	N/A	N/A	1		1,800			12,000	NONE	4	20.8	115
SALINA	NONE	N/A	N/A										
SAN LUIS				4					2,200		4	17.0	2,200
SENECA								16.8					
SMITH MOUNTAIN	NONE	N/A	N/A	NONE	N/A	N/A	NONE	N/A	N/A	NONE	5	15.1/19.1/20.7	VARIES
TAUM SAUK						450			6,550				
WALLACE	NONE	N/A		NONE			NONE	N/A		NONE			
YARDS CREEK			1,500				1	25.7	1,350		1	29.0	2,375
FOREIGN PROJECTS													
DINORWIG	1	14.6	5,560	1	16.4	1,453	1	18.0	1,738	NONE	6	43.0	557
FFESTINIOG	NONE	N/A	N/A	2	12.3	656	4	14.4	1,110	NONE	4	23.0	754
TURLOCH HILL	1	9.38	348	1	21.0	1,916	NONE	N/A	N/A	NONE	4	N/A	N/A
LE TRUEL							1						
MONTEZIC	1	14.5	2,076				2	17.6	1,857	NONE	4	18.2/36.1/62.6	
BAJINA BASTA													
MINGHU										2(311.6 FT)	2		1705/1838
NUMAPARRA	3	17.4	1,488	NONE	N/A	N/A	1	6.0	4,690		3	41.4	2610-2643
SHINTOYONE	5	18.7	1,148	NONE	N/A	N/A	2	18.7	6,181	2(26FT X 298FT)	5	18.7	951-1033
MASEGAWA													
OKUYAHAGI PLANT 1													
OKUYAHAGI PLANT 2													

PROJECT DATA SUMMARY
TABLE 10 (cont.)
WATER CONVEYANCE SYSTEM

NAME	POWERHOUSE INLET VALVE DETAILS	VALVE MANUFACTURER	VALVE CLOSING METHOD	VALVE FLUID OPER./SEAT	TIME OPEN/CLOSE (SEC)	DRAFT TUBE GATE DETAILS	DRAFT TUBE GUARD VALVE NUMBER	DRAFT TUBE GUARD VALVE DIA. (FT)	DRAFT TUBE GUARD VALVE TYPE	LOW PRESSURE SURGE TANKS NUMBER	LOW PRESSURE SURGE TANKS LENGTH
DOMESTIC PROJECTS											
BATH COUNTY	114" SPHERICAL	ALLIS-CHALMERS	HYDRAULIC	OIL/WATER	40/60	SLIDING BULKHEAD TYPE	NONE	N/A	N/A	NONE	N/A
BEAR SWAMP	132" SPHERICAL	HITACHI	HYDRAULIC	OIL/WATER	30/30	SLIDING BULKHEAD TYPE	NONE	N/A	N/A	NONE	N/A
BLENHEIM GILBOA	72"SPHERICAL	HITACHI	HYDRAULIC		30/30	SLIDING BULKHEAD TYPE	NONE	N/A	N/A	NONE	N/A
CABIN CREEK	NONE	N/A	N/A	OIL/WATER	120/120		2	4.99	SPHERICAL	NONE	N/A
CARTERS	NONE	N/A	N/A			14 FT X 29 FT SLIDE	NONE	N/A	N/A	NONE	N/A
CASTAIC	104" SPHERICAL	HITACHI	HYDRAULIC	OIL/WATER		15 ton BULKHEAD	NONE	N/A	N/A	NONE	N/A
FAIRFIELD	NONE	N/A	N/A	N/A		2 X 15 FT X 26 FT SLIDE	NONE	N/A	N/A	NONE	N/A
HELMS	95" SPHERICAL	HITACHI	HYDRAULIC	WATER/WATER	120/120	DOOR W/ HYDRAULIC OPERATOR	NONE	N/A	N/A	1	969 FT
HORSE MESA	NONE	N/A	N/A	N/A		3 X 24 FT X 12 FT	NONE	N/A	N/A	NONE	N/A
JOCASSEE	NONE	N/A	N/A	N/A			NONE	8.99	SPHERICAL		
LEWISTON	NONE	N/A	N/A	N/A		STOPLOGS	NONE	N/A	N/A	NONE	N/A
LUDINGTON	NONE	N/A	N/A	N/A			NONE	N/A	N/A		
MORMON FLAT	NONE	N/A	N/A	N/A		3 X 17 FT X 15 FT	NONE	N/A	N/A	NONE	N/A
MOUNT ELBERT (UNIT 1)	NONE	N/A	N/A	N/A		SLIDING BULKHEAD	NONE	N/A	N/A	NONE	N/A
(UNIT 1)	NONE	N/A	N/A	N/A			NONE	N/A	N/A	NONE	N/A
										NONE	N/A
MUDDY RUN	NONE	N/A	N/A	N/A			?	9.50	SPHERICAL		
NORTHFIELD MOUNTAIN	114" SPHERICAL	BLH	HYDRAULIC	OIL/OIL			NONE	N/A	N/A		
RACCOON MOUNTAIN	120 SPHERICAL	ESCHER WYSS	HYDRAULIC	OIL/WATER	45	NONE	NONE	N/A	N/A		
SALINA	BUTTERFLY			OIL			NONE	N/A	N/A		
SAN LUIS	156" BUTTERFLY	MITSUBISHI	HYDRAULIC	OIL/N.A.	183	BULKHEAD	8	13.00	BUTTERFLY	NONE	N/A
							NONE	N/A	N/A		
SENECA	114" SPHERICAL	BLH	HYDRAULIC	OIL			3	9.51	SPHERICAL	NONE	N/A
SMITH MOUNTAIN (UNIT 3)	NONE	N/A	N/A	N/A		3 X 21 FT X 17 FT	NONE	N/A	N/A	NONE	N/A
(UNITS 1 & 5)	NONE	N/A	N/A	N/A		2 X 21 FT X 17 FT	NONE	N/A	N/A	NONE	N/A
TAUM SAUK	108" SPHERICAL	ALLIS CHALMERS	HYDRAULIC	OIL/WATER			NONE	N/A	N/A		
WALLACE	NONE	N/A	N/A	N/A			NONE	N/A	N/A	NONE	N/A
YARDS CREEK	84.5" SPHERICAL	ALLIS CHALMERS	HYDRAULIC	WATER/WATER	180/180	SLIDING BULKHEAD TYPE	NONE	N/A	N/A		
FOREIGN PROJECTS											
DINORWIG	98.4: SPHARICAL	BOVING	WEIGHT	OIL/WATER			6	12.30	BUTTERFLY	1	N/A
FFESTINIOG	70" STRAIGHTFLOW	ENGLISH ELECTRIC	HYDRAULIC	WATER	48	2-SLIDING BULKHEAD	NONE	N/A	N/A	NONE	N/A
TURLOCH HILL	67" SPHERICAL	VON ROLL	HYDRAULIC	WATER	55/55	FLAP	NONE	N/A	N/A	NONE	N/A
LE TRUEL	SPHERICAL		HYDRAULIC			6 FT X 9 FT ROLLER	NONE	N/A	N/A	2	26' DIA
MONTEZIC	80.7" SPHERICAL	NEYRPIC	HYDRAULIC	OIL	60/60		NONE	N/A	N/A		374' x 33'
BAJINA BASTA	86.6" SPHERICAL	TOSHIBA	HYDRAULIC		/30		NONE	N/A	N/A		
MINGHU	SPHERICAL	HITACHI	HYDRAULIC				NONE	N/A	N/A	NONE	N/A
NUMAPARRA	94.5" SPHERICAL	HITACHI	HYDRAULIC	OIL/WATER	150/150	3 X 13 FT X 3 FT SLIDE	NONE	N/A	N/A	NONE	N/A
SHINTOYONE	137.8" SPHERICAL	TOSHIBA	HYDRAULIC	WATER/WATER	70/70		NONE	N/A	N/A	NONE	N/A
MASEGAWA	NONE	-	-	-			NONE	N/A	N/A		
OKUYAHAGI PLANT 1	118.1" BUTTERFLY	TOSHIBA	HYDRAULIC	OIL/N.A.			NONE	N/A	N/A		
OKUYAHAGI PLANT 2	90.6" SPHERICAL	HITACHI	HYDRAULIC	OIL/WATER			NONE	N/A	N/A		

PROJECT DATA SUMMARY
TABLE 11
POWERHOUSE DATA

NAME	POWERHOUSE TYPE	POWERHOUSE LENGTH (FT)	POWERHOUSE WIDTH (FT)	POWERHOUSE HEIGHT (FT)	MAIN CRANE TYPE	MAIN CRANE CAPACITY (TON)	OTHER CRANE DETAILS	OTHER CRANE CAPACITY TON)
DOMESTIC PROJECTS								
BATH COUNTY	CONVENTIONAL SURFACE INDOOR TYPE	490	150	200	BRIDGE CRANE	760	HIGH SPEED BRIDGE CRANE	200
BEAR SWAMP	UNDERGROUND	227	79	152	BRIDGE CRANE	616	AUX. CRANE	2@30
BLENHEIM GILBOA	REINF. CONC. SEMI-OUTDOOR TYPE	366	175	132	DBL. CANT.GANTRY	510	AUX. BRIDGE CRANE HOOKS	3,2@10
CABIN CREEK	SEMI UNDERGROUND	143	100	107		90	AUX BRIDGE	15
CARTERS	CONVENTIONAL SURFACE INDOOR TYPE	362	114	159	BRIDGE	360	2 MAIN & 2 AUX. HOOKS	2@25
CASTAIC	CONC. STRUC. 2/3 UNDERGROUND	600	187	190	BRIDGE (2)	375	GANTRY	30
FAIRFIELD	SEMI-OUTDOOR CONSTRUCTION	520	150	100	GANTRY CRANE	185	GANTRY	30
HELMS	UNDERGROUND	336	83	144	LANDEL BRIDGE	2 x 270		
HORSE MESA	CONVENTIONAL INDOOR	83	75	93	NONE	N/A	N/A	N/A
JOCASSEE								
LEWISTON	SEMI-OUTDOOR TYPE	974	233	160	GANTRY CRANE	168	BRIDGE CRANES	VARIOUS
LUDINGTON		576	171	106	GANTRY	360		
MORMON FLAT	CONVENTIONAL INDOOR	94	72	98	NONE	N/A	N/A	N/A
MOUNT ELBERT	SEMI-OUTDOOR	146	104	182	BRIDGE CRANE	450	AUX	10
MUDDY RUN	OUTDOOR TYPE W/ GEN. DECK	600	140	80				
NORTHFIELD MOUNTAIN	UNDERGROUND CAVERN	328	70	155	GANTRY CRANE	350	AUX.	25
RACCOON MOUNTAIN	UNDERGROUND	490	72	165	BRIDGE CRANE	2 x 220	2-AUX	25
SALINA								
SAN LUIS	INDOOR	483	97	49	ONE BRIDGE / TWO TROLLEY	2 x 175		50 W/10 AUX
SENECA	FULLY ENCLOSED	230	70	138				
SMITH MOUNTAIN	SEMI-OUTDOOR	N/A	N/A	N/A	GANTRY PACECO	350	AUX.	30
TAUM SAUK	REINF. CONC. SEMI-OUTDOOR CONST.	150	88	80	GANTRY CRANE	175		
WALLACE	INDOOR	N/A	140	65	BRIDGE	300	AUX.	25
YARDS CREEK	REINF. CONC. SEMI-OUTDOOR	150	105	78	GANTRY CRANE	327	AUX. HOIST	25
FOREIGN PROJECTS								
DINORWIG	UNDERGROUND	588	77	168	BRIDGE(TWO)	275	AUX.	10
FFESTINIOG	SURFACE INDOOR	236	72	177	BRIDGE	2 x 122	AUX.	2 x 30
TURLOCH HILL	UNDERGROUND	269	75	98	BRIDGE	2 x 70	AUX.	50
LE TRUEL						60		
MONTEZIC	UNDERGROUND	476	82	157	SEMI-GANTRY	2 x 125	AUX.	20 x 5
BAJINA BASTA								
MINGHU	UNDERGROUND	417	70	132	BRIDGE	2 x 250	AUX.	2 x 35
NUMAPARRA	UNDERGROUND	423	66	131	BRIDGE	2 x 190		
SHINTOYONE	UNDERGROUND	451	70	69	BRIDGE	2 x 256	BRIDGE	70
MASEGAWA								
OKUYAHAGI PLANT 1								
OKUYAHAGI PLANT 2								

Appendix B

FIELD VISIT REPORTS

Appendix B consists of notes made during field visits to each of the plants studied. As far as possible, utilities were given the opportunity to comment on the notes and to revise where necessary.

ELECTRIC POWER RESEARCH INSTITUTE
HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-1 - BATH COUNTY

VISIT DATE - 13 MARCH 1986

OWNER: Virginia Electric Power Company (VEPCO)

OWNER'S REPRESENTATIVES:

Sidney Bragg	- Mechanical Engineer
Richard Bird	- Computers
John Cormier	- Civil Engineer
Charlie Davenport	- Superintendent, Technical Services
David Glendinning	- Quality Assurance
Lew Johnston	- Manager
Charles Propst	- Mechanical Engineer
K. H. Staiger, Jr.	- Superintendent, Maintenance
T. G. Ward	- Instrument Supervisor

EPRI REPRESENTATIVES:

A. Ferreira	- EPRI	- Coordinator
B. E. Sadden	- MKE	- Civil Engineer
J. L. Carson	- MKE	- Mechanical Engineer
W. R. Moon	- MKE	- Electrical Engineer

GENERAL AND PLANT DESCRIPTION

Bath County Plant is located approximately eight miles north of Mountain Grove in Bath County, Virginia and has just entered service. The upper reservoir stores approximately 22,500 acre-feet behind a 2200-foot long, 460-foot high earth and rockfill structure. It incorporates a fuse plug spillway of erodible fill 260 feet long, which is design to wash out at El. 3323 (three feet above maximum pool). The lower reservoir is formed by an earth and rockfill structure 2400 feet long and 140 feet high with associated outlet works and a spillway capable of passing 60,000 cfs.

The hydraulic passages consist of three 19' x 58' intakes and three power tunnels consisting of 3700 feet of 28.5-foot diameter low pressure tunnels, 986-foot vertical shafts and three high pressure 28.5-foot diameter tunnels bifurcating into six 18-foot diameter steel penstocks. Surge tanks, which are 44 feet in diameter and 330 feet high, are located out the end of each low pressure tunnel.

The powerhouse has six 65 foot wide bays each containing a 350-MW pump/turbine generator/motor. Ratings of each unit are:

	As Turbine	As Pump
Net Head	1262 ft	1270 ft
Output	350 MW	4500 cfs
Speed	257.14 rpm	257.14 rpm

Bath County is the largest capacity pumped storage scheme in the world. The commercial start was December 18, 1985 for Units 1 through 5 and December 31, 1985 for Unit 6. The latter startup was delayed due to transformer problems.

At the time of the visit, the contractor was still removing his offices and plant yards. There was some work underway in the tunnels and generally the plant was undergoing finishing touches.

OPERATIONAL ASPECTS

Normal operating range of the turbines is 280 to 360 MW at low heads and 340 to 450 MW at high heads. A load of 500 MW was reached briefly, but operation was very rough and insufficient data exist for determining if this is a realistic load for either the turbine or generator.

Pumping is performed at best efficiency wicket gate position as determined by the model tests.

Pumping is done at night. During winter and summer, generation continues throughout most of the day. During spring and fall, generation occurs in the morning and evening, with some synchronous condensor operation during the afternoon and late evening. The plant is dispatched from Richmond, Virginia. At present, the units are not on load control but will be at some time soon. Operators think that synchronous condenser operation will increase in the future.

The ratio of generating to pumping energy, corrected for reservoir levels and station service, has been just over 0.80 for 1986.

There are some restrictions in operation. For instance, the wicket gates leak so badly that breakaway occurs and the minimum head difference across the valve that can be reached when filling the spiral case is 375 psi. It is therefore impossible

to meet the precondition for opening the valve seals at less than 5 psi head difference. An opening has to be done at 375 psi. The time of the spherical valve opening is 40 seconds. The valve closing time is 60 seconds.

The lower limits on the operation of the units of 280 MW at the low head and 340 MW at the high head have been determined based on audible cavitation and pressure surges in the draft tube. The high head generation limit of 450 MW is based on main step-up transformer restrictions.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

Very little maintenance experience is available because the station has only just come on line. However, the staff propose an 18-month maintenance interval at which time an inspection of all the parts would be carried out, taking four to six weeks. The variation in time would depend on whether the head gate should be inspected. Intakes and tunnels will be inspected by a remotely operated vehicle.

There is a computer logging system which tracks the history of the major components.

The operation and maintenance crew comprises 40 electrical and mechanical technicians, seven instrument technicians, four computer technicians, and five engineers. There is an operations superintendent, five shift supervisors, and 20 operators. In addition, there are four technicians classed as environmental, including geotechnical technicians.

TURBINE PROBLEMS

The depression air system in the turbines was not satisfactory because the rapid influx of 200 psi depression air through the 10-inch valve lifted and damaged the shaft seal. The admission system has been modified to introduce depression air through a 2-inch pipe below the runner and a 3-inch pipe above the runner which has slowed the time to depress from thirty to ninety seconds. The original 10-inch depression air pipe is not used now.

The standpipe in the tailrace, which measures the depression level, was subject to the dynamic effects of water when the depression air was introduced. The water in the draft tube was splashing into the standpipe and activating the switch. The solution was to introduce time delays and future designs should make the standpipe longer and of greater diameter.

There have also been a few non-catastrophic thrust bearing failures (one on Unit 3 and four on Unit 5). Introduction of cold oil at the thrust bearing during unit startup caused the shoes to deflect and decrease the oil film thickness. This and other problems with the lift system, thermal ratcheting, etc. are thought to be the main causes of the thrust bearing failures. An oil temperature control system has been installed on all units.

Testing with the lift pumps shutoff indicates that the use of the temperature control system and modifications to the lift system should reduce the chances of failure. The units will be operated on a trial basis without the lift system running continuously and, if successful, permanent operation will be without continuous high lift.

There is leakage through the wicket gates around the stem seals, around the wicket gate seals, and the top and bottom edges of the gates. In fact, there is so much leakage that the unit accelerates upon opening of the spherical valve even though the wicket gates are closed. There have been a number of problems with the adjustment of the wicket gates. The upthrust collar was not functioning properly, which allowed the gates to raise and gall the upper facing plate.

There was a wearing ring failure on Unit 1 and in the search for a cause, wood, bolts, welding rod, wood shavings, etc. were removed from the unit. Misadjustment of the servomotors at initial operation caused the bearing to move when the wicket gates were squeezed shut. This, in turn, caused the runner wearing rings to touch and seize.

Additional problems with the upper stationary wearing ring resulted in all upper wearing rings being replaced. The upper stationary ring is shrunk to the outer bore of the shaft seal support housing and doweled to prevent rotation or slippage. After failures of both Units 2 and 3 rings due to cracks, the manufacturer believes that the mounting bore is moving relative to the ring. This causes the dowel to work in the hole, causing high localized stresses and cracks. A new bolted segmented ring will be used to replace the old one piece shrunk ring.

The turbine guide bearing clearances were initially too small, resulting in high bearing temperatures. The clearance was increased and the oil ports made larger to rectify the problem.

Pressure surges limit the minimum generator output to 300 MW. Air injection was tried using the depression system which helped, but the air compressor capacity is not sufficient for sustained operation.

Shaft seals have performed inconsistently. Staff indicate that the shaft seal is poorly machined together with several other flaws which allow the sealing element (carbon) to tilt. It was also suggested that part of the problem might be due to the water quality. After a flood, an immediate clogging of the filters occurred. Potable water is used for testing.

GENERATOR PROBLEMS

The generator originally did not meet the contract heat rise guarantee for 60°C and 80°C heat rise at 100% and 115% output, respectively. The air baffles were modified as a result. Staff indicate that the new baffle system support structure was poorly fabricated and had a natural frequency of 120 Hz. The combination of high static stress and resonance caused some of the supports to fail. Nuts and bolts also came loose, causing damage to Units 2 and 4. The rotors from Units 2 and 4 were removed and the damaged stator iron repaired. The units are now being inspected weekly until the support structures are modified to relieve the static and dynamic stresses. Even with the new baffle system, the generators still do not meet the heat rise guarantee. A new airfoil design is planned for test in July 1987 that will force more air through the stator core. As a result of testing the baffle support structure, it has become evident that the upper guide bearing supports were not stiff enough to properly restrain the shaft. This lowered the first critical speed down to less than runaway speed and in some cases to just above running speed. The generator manufacturer is proposing the use of hydraulic snubblers to increase the stiffness. This and other options are now under review. A problem is developing with corona damage in the stator windings. Insufficient data exist at this time to determine the severity of the damage.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

There have been two high voltage bushing failures on the 500-kV side of one step-up transformer. There has been also a secondary winding failure on another transformer which had to go back to the factory for repair.

Plant operators feel that the unit control boards on the generator floor are not necessary. The duplication resulted in many extra startup procedures and unnecessary activities. They are only needed when troubleshooting, and at that time,

there is less communication from the unit control board to the control room to maintain.

CONTINUING CIVIL AND HYDRAULIC PROBLEMS

A vortex was reported while the upper pool water level was at El. 3245 (30 feet above minimum pool) and four units were in operation. The conditions occurring on that day have not been duplicated since, and the vortex has not reoccurred.

A penstock liner buckled after three days of operation, a well known failure described in a number of published papers. The original design criteria called for the ability to dewater tunnels independently from each other. Plant operators suspect two causes for the penstock problems. Firstly, the penstock structure may not have adequate strength to withstand the external pressure and secondly, drainage systems did not function properly, permitting buildup of pressure. It has also been found that hydraulic pressures exceeding confining strength of the rock permitted high pressure water to migrate, thereby imposing external pressure on the penstocks. The solution adopted was to unwater the entire system and grout three geologically poor areas with 60-foot long holes at 10-foot centers. Other areas were grouted less extensively. A total of 22,000 holes were drilled and 100,000 sacks of cement were used. The program was successful in restricting leakage but not in stopping the pressure transfer. Therefore, the station had been denied the flexibility of unwatering each penstock in isolation. In addition, the operators acknowledge that drawing down of all penstocks will have to be very carefully done. They have closed the gates on one Sunday and measured 6,000 gpm of leakage, mostly in Tunnel 3. At the time of the visit, there was a limited grouting program in operation.

The dams perform satisfactorily, even during raising of the reservoir water level by 50 feet in 24 hours during floods in November 1985, There has been some slopes erosion in the lower reservoir but the erosion was not excessive.

Although the lower reservoir was carefully calibrated the upper was not. As a part of the preparation for commercial operation, staff are calibrating the upper reservoir, using the lower reservoir as a base.

During construction, there was a large slide in the cut at the right abutment of the dam. A slope was excavated but was not continued further upstream because during November 1985 another slide slightly upstream of the cut slope occurred. The whole slope now being re-excavated to ensure no more slides occur.

There are no indications of major powerhouse leakage despite its deep submergence.

COMMENTS AND IDEAS

The operating crew is of the opinion that the quality of the main equipment supplied is good, while the quality of the ancillary equipment is inferior.

The coatings used over carbon steel in the water passages are easily damaged in the course of any maintenance work in the penstock, spiral case and draft tube. Subsequent coating repair work is difficult to schedule with startup in progress.

Small piping is also coated, and in some areas, this coating comes off in sheets, causing startup delays. Since much of the smaller piping is embedded, replacement if and when required will be a major undertaking.

The staff recommends stainless steel for all embedded water passages as a minimum. In this case, startup would have been smoother and there would be less worry about the future. As a general rule, staff caution against attempts of saving money on insignificant items.

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CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-2 - BEAR SWAMP

VISIT DATE - 21 NOVEMBER 1985

OWNER: New England Power Company

OWNER'S REPRESENTATIVES:

Charles Harrington	- Superintendent of Maintenance (not on site during visit)
Richard H. Lang	- Supervisor (Overhaul Project)
Mark Rapf	- Engineer

EPRI REPRESENTATIVES:

A. Ferreira	- EPRI	- Coordinator
B. E. Sadden	- MKE	- Civil Engineer
J. L. Carson	- MKE	- Mechanical Engineer
W. R. Moon	- MKE	- Electrical Engineer
J. Cogan	- MKE	- Geotechnical Engineer

GENERAL AND PLANT DESCRIPTION

Bear Swamp is a pumped storage project located on the Deerfield River near Florida & Rowe in Massachusetts.

The upper reservoir is formed by three earth and rockfill dikes, the largest one of which is 150 feet high.

The lower reservoir is formed by a 125-foot high earth dam across the Deerfield River incorporating a gated concrete spillway.

The waterways comprise a vertical concrete lined shaft and a horizontal concrete lined tunnel which bifurcates into two steel lined pressure tunnels, each leading to the turbine, and two shotcrete lined tailrace tunnels connected to their respective draft tubes.

The powerhouse is an underground type containing two reversible Francis units, each with the following nameplate ratings:

	As Turbine	As Pump
Net Head	720/750 ft	865 ft
Output	298/320 MW	4430 cfs
Speed	225 rpm	225 rpm

The underground powerhouse is 227 feet long, 152 feet high and 79 feet wide. A 606-ton bridge crane spans the powerhouse. Transformers are located at the surface next to the lower reservoir.

On the visit day, the plant was in the process of a complete overhaul of one of the units by Hitachi, who had subcontracted the work to Eagle Construction.

Most of the powerhouse generator floor was taken up by the turbine and generator parts, so it was difficult to move around. A sandblasting enclosure had been constructed around the head cover and runner.

OPERATIONAL ASPECTS

Bear Swamp is operated remotely, but a maintenance personnel usually calls in once per day.

Output is limited to wicket gate openings from 50% to 80%.

The units are not operated as synchronous condensers. One attempt was made during construction, but was not satisfactory. No further attempts were made.

The plant basically operates on a daily cycle with two to three starts per day.

Brakes are applied at 20 rpm.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

Annual overhaul lasts two to three weeks including inspection of the clearances of the runner. Cavitation repair has been carried out only three times in ten years.

The first major overhaul was underway (after 11 years) and was scheduled to take 19 weeks per unit. The background to the overhaul is:

- At eight years, generator and turbine manufacturers submitted reports about the advisability of a full service overhaul.

- Vibration of wicket gates in pumping mode was a concern.
- Downstream seals of spherical valves needed replacement.
- Generator wedges needed work.
- Turbine packing boxes needed repair.

TURBINE PROBLEMS

As stated elsewhere, cavitation has not been identified as a major problem. No records of the weld material placed have been kept. The second repair was performed under the manufacturer's supervision.

Cavitation damage had occurred on the underside of the head cover.

Before overhaul, at certain times, a ringing noise was heard from the wicket gates area. Initially it was considered that wicket gate surface roughness may be a problem and so an epoxy coating was applied. This did not cure the problem which was found to be the vibratory resonances at the 13th harmonic. An alternative solution was to redesign the gates. Since there was no guarantee that this would solve the problem, this idea was abandoned. Instead, it was decided to stiffen the operating mechanism by an increase of linkage size, a modification of bearing clearances, and an increase of bushing sizes.

The shaft sleeves were replaced because of scouring caused by resin rings and a new stainless steel packing box was used. The resin seal ring was changed to carbon seal several years earlier.

Wearing rings on the turbine were changed to reduce leakage and increase efficiency.

There are no plans to conduct efficiency tests, though there is a 15-year program to upgrade efficiency of New England Power hydro plants.

A vibration monitoring system has been added, principally because the station is unmanned. The hydro station at Harriman receives the alarm from this system.

Embedded equalizing piping connections to the draft tube keep breaking due to vibration of the draft tube liner.

There was a great deal of corrosion of the runner and wicket gates, which staff believed to be due to the high oxygen content of the water.

GENERATOR PROBLEMS

Prior to the recent unit major overhaul, loose wedges were noted on both the generator/motors and the starting motors. This was not a major problem, but a concern for the future. The wedges were replaced per manufacturer's instructions, with standard backing strips. New England Power expects to get 10-20 years life from the new wedges.

The generator air coolers were oversized, resulting in excessive temperature fluctuation, particularly during starting. Because such fluctuation affects wedge stability and other factors, thermostats and control valves were added to keep down the temperature cycling.

There have been slight signs of corona "white powder" on coil end phase splits but no damage.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

The unit circuit breakers, manufactured by Brown Boveri Co., have had no major problems, but frequent maintenance has been necessary. The breakers are rated for 3000 close-open (C-O) cycles before a major overhaul is necessary, about three years of normal operation. Some air nozzle cracking on the air blast circuit breakers has occurred and these have been modified several times. Also, main seal air leaks have been a problem.

There have been no significant problems with the main power transformers or with the switchyard equipment, although the transformers are gassing. They are being monitored.

The downstream seal of the shutoff valve became misaligned due to wear and it was necessary to operate the valve using the upstream seal for one year.

The rubber in one liquid rheostat deteriorated and had to be replaced.

CONTINUING CIVIL AND HYDRAULIC PROBLEMS

At a high gate openings (80%+) there is a draft tube surge with a period of about one-and-a-half seconds. Once this surge commences, output must be cut back thus limiting the unit output. Injection of air was considered, but air demand at only one unit could be satisfied with the available equipment, so the idea was abandoned.

There was a rockfall of an anchored slope above the leads tunnel entrance (4-9-84) which damaged the cross-over leads for the transformers. Also damaged were the leads from the emergency generator so no power was available for sump pumps. Emergency power was required quickly to prevent flooding.

The upper reservoir was only drained once, during the recent overhaul. A visual inspection of the penstock from top and bottom resulted in the decision not to inspect the complete penstock lining with a portable platform.

At one time, startup was attempted with water level in the turbine still depressed. The resulting air bubble lifted the draft tube gates, which snapped their hoist cables when the gates dropped. One gate caught on the ledge and the other fell, damaging it.

COMMENTS AND IDEAS

All phases of each unit circuit breakers are cooled together. If the utility were to build another plant, all phases would be cooled separately as there have been problems of overheating.

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CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-3 - BLENHEIM-GILBOA

VISIT DATE - 20 NOVEMBER 1985

OWNER: New York Power Authority (NYPA)

OWNER'S REPRESENTATIVES:

James J. McCarthy, Jr.	- Resident Manager
Richard S. Siola	- Superintendent of Power
Richard H. Davis	- Mechanical Superintendent
James E. Webster	- Electrical Superintendent
Carleton F. Payne	- Chief Operator
Steve Schildhorn	- Civil Engineer

EPRI REPRESENTATIVES:

A. Ferreira	- EPRI	- Coordinator
B. E. Sadden	- MKE	- Civil Engineer
J. L. Carson	- MKE	- Mechanical Engineer
W. R. Moon	- MKE	- Electrical Engineer
J. Cogan	- MKE	- Geotechnical Engineer

GENERAL AND PLANT DESCRIPTION

Blenheim-Gilboa (B.G.) is a conventional pumped storage plant located about 40 miles southwest of Albany, New York. The upper reservoir atop Brown Mountain is formed by an 11,900-foot long earth dike with a maximum height of about 162 feet above bedrock (109 feet above original ground). The lower reservoir is formed by an earth and rockfill dam across Schoharie Creek with a maximum height of 100 feet. The dam has a 425-foot long concrete lined spillway controlled by three gates. The powerhouse is a semi-outdoor type reinforced concrete structure 526 feet long, 172 feet wide and 132 feet high containing four Francis type units.

Nameplate rating of each unit is as follows:

	As Turbine	As Pump
Net Head	1002 ft	1085 ft
Output	250 MW	2840 cfs
Speed	257 rpm	257 rpm

A 510-ton gantry crane with two 255-ton trolleys traverses all the units. The water conduits consist of a 1055-foot long, 28-foot diameter vertical shaft from an ungated intake structure on the floor of the upper reservoir and 1049-foot long, 28-foot diameter concrete lined tunnel. At the downstream end of the tunnel a manifold is connected to four penstocks. Each penstock is 12-foot diameter and 1960 feet long, of which 1780 feet are steel lined.

The project was constructed between July 1969 and July 1973.

On the visit day, the plant was operating normally; no maintenance was in progress.

OPERATIONAL ASPECTS

The use of B-G is determined by the needs of each customer of NYPA who pays a fixed amount per month for pumped storage capability. These customers have first call on Blenheim-Gilboa. If they do not call for use of B-G then NYPA uses the power. Under those conditions the plant is usually operated in conjunction with the Lewiston/Moses complex.

Demand for B-G use is scheduled 24 hours in advance. Typically a unit will undergo two starts/two stops per day as a generator and one start/one stop as pump (six mode changes per day), generating during morning and afternoon peaks and pumping at night and at weekends.

The daily cycle of the plant usually results in an 18 to 30-foot change of reservoir elevation. The weekly cycle results in 40-foot variation so extra pumping is carried out at weekends to bring the upper reservoir up to maximum elevation on Monday morning.

The plant utilization is increasing. At the beginning of operation in 1973, plant generation factor was 6%; in 1984 it was 25%.

Blenheim-Gilboa normally operates at outputs from 200 to 260 MW under block loading as called for by the dispatcher, although they have the capacity to regulate speed.

A constraint in operation is that between 100 and 200 MW there is a hydraulically induced vibration in the draft tube. Pumping is performed at best efficiency. Pumping input is 273 MVA to 295 MVA; generating output is rated at 250 MW but has been 275 MW at the highest upper reservoir level.

There is occasional use as a synchronous condenser, averaging less than 10 hours per month, mostly in the spring and the fall.

Operational times for B-G are as follows:

- (Generating) 90/100 secs. from standstill to synchronization
  30 secs. for loading in emergency
  10 mins. for normal loading
- (Pumping) 8 mins. from standstill to pumping
  22 secs. for pumping to normal disconnecting
- Braking was set initially at 25% speed but brakes were wearing badly, so braking is now commenced at 4% (10 rpm).
- Spherical valves open or close in 30 secs.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

Each unit has received one major overhaul, taking about 13 weeks. The sequence commenced in 1982-1983. Of the 13 weeks, two weeks was for removal of the head cover which must be split into four pieces. NYPA are scheduling three weeks for maintenance per year for each unit for inspection and for cavitation repair and breaker servicing.

Plant availability has been about 94% from the first full year of operation until the major overhauls. Including the major overhauls it now stands at 92%. Current maintenance for the units is three weeks per year when little dismantling is carried out. At this time most clearances are checked, fluids and filters cleaned, ancilliaries checked, and as much of the machine as possible is visually inspected. Included with this report is a typical inspection record for Unit 2 pump-turbine for maintenance in 1981. It is indicative of the detail of the annual work. The Authority plans to reduce the frequency of routine maintenance, thereby increasing the plant availability to 95%. The schedule to achieve this will be to use Unit 1 as a test unit. It will be operated on the basis of first on and last off to reveal patterns of wear. It will be routinely inspected every year with a three-week period scheduled. Repair of other units will be scheduled in accordance with results available from Unit 1.

The maintenance crew consists of 27 men who do all work on a basic day shift. There are also 17 or 18 operators on a three shift system. NYPA has also occasionally contracted for four outside millwrights.

TURBINE PROBLEMS

As mentioned above, when generating between 100 MW and 200 MW, there are hydraulically induced vibrations in the draft tube. No attempt has yet been made to solve the problem by air injection.

Runners are fabricated of mild steel clad with stainless steel in areas subject to cavitation. Over the period of operation of the plant, the area of stainless steel cladding has been extended considerably and substantial contouring has been done. In 1974, 175 lbs. of weld material per unit was being used for repair. In 1985, 50 to 60 lbs. of weld material per unit was used. Significant cavitation damage occurred on the crown between the buckets. This was repaired by plug welding stainless tiles in place.

NYPA will study the feasibility of replacing the runner of one unit with a runner optimized for pumping. This is because most of the time they generate with three units but pump with four. The "pump" unit would always be the last one to generate.

Equalizing lines, which drain the area between the head cover and the runner, have experienced breakage from vibration or cavitation. They have now been removed and units have run two years without noticeable problems. Before removal, they had been inadvertently closed for some time.

The head cover deflects up to .040 inch, particularly when the turbine is being pressurized.

There was a continuous problem with wicket gate rubber seals until the first overhaul. At the recent overhaul, bronze strips were inserted above with rubber underneath and no other problem has occurred. Wicket gate bushings on one unit have been changed from grease lubricated to self-lubricated.

The float switches, which detect draft tube water level and which are used for depression air control, was troublesome. Reworking of the float pivot shafts reduced the frequency of difficulty to a minimum and the problem is kept under control by annual maintenance.

GENERATOR PROBLEMS

An early problem was the faulty connections from the generator/motor leads to the isolated phase bus. A number of insulated joints were found to be running extremely hot. Use of an infrared heat detector identified all the hot joints, and these joints have been removed, refitted to increase the contact surface area, and reinsulated. All joints are checked with the infrared detector on a routine basis in the pump mode to establish which joints are either failing or need immediate replacement.

The Power Authority is reversing the stator winding connections to the line buses and neutral buses. This results from unequal corona damage to the high voltage end of the windings compared to those in the neutral end. On these units, the neutral buses are brought out 180° from the line buses. It was necessary to disconnect the ring buses and rotate them 180°. It was suggested that, during project design, provisions be made to permit convenient reversing of the connections, such as bringing them out adjacent to each other and some method of changing the bus connections.

Rewedging of the stator windings was suggested by the manufacturer after seven years. In fact, it was performed after nine years (at the major overhaul) and has been done a second time.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

Early in the life of the plant, a unit air-blast circuit breaker, rated 17 kV, 12,000 A, suffered destructive failure. This was caused by the jamming of a contact actuating rack and pinion gear, with the result that the contact only partially closed on unit synchronization. The breaker was repaired on site and the problem has not reoccurred. Unfortunately, in these breakers contacts continually wear out and, in general, require frequent maintenance due to the number of operations. Spare parts are no longer available from the manufacturer, so the Power Authority has to fabricate their own spares. Each breaker is carefully inspected every two months and given a complete overhaul annually.

These are the same breakers that are used in Northfield and Mt. Elbert. NYPA is still using the same breakers but is considering replacing them. They feel that there never were breakers manufactured specifically for arduous pumped storage use.

One main transformer has, at times, "gassed" badly. When the unit is removed from service and tested, no fault can be found. On return to service, it will operate satisfactorily for a period of time before starting to gas again. This transformer is watched closely and inspected frequently.

One transformer failed due to a poor internal connection. The transformer was repaired by Westinghouse. After it was returned to the plant, tests indicated existence of an internal ground. Repaired again, the ground still existed so the Power Authority purchased a new transformer to replace the failed unit. On receipt, it was found to be damaged during shipment, and was returned to BBC for repair. It has now been returned to the plant and is ready to be put into service. Total elapsed time from the first failure was almost six years. A spare transformer was furnished during construction and has been used during this period.

Apart from the shorting and explosion of a switchyard 345-kV metering and relaying current transformer, there have been no significant electrical problems in the switchyard. The towers of Cor-Ten steel, including transmission line towers have had problems. Water continues to get between the plates at joints and the rust builds up, eventually popping the bolts. A method of repair has been developed and implementation has started, but NYPA would probably not recommend a similar detail of overlapping Cor-Ten steel.

The original water level transducer (analog type) installed at the upper reservoir was not reliable and had to be replaced. Equipment to accurately measure the upper reservoir water level and transmit the data to the plant in digital form replaced the original analog equipment. This has been accurate and is reliable enough to permit volumetric water control of pumping and generating.

Under the original design the transformer cooling fans have to be engaged while a main power transformer is energized even while not under load. NYPA operating staff would prefer a rating which would require fans turned on only when the transformer is loaded (OA/FA/FOA).

The differential pressure switch across the spherical valve gave some early trouble. Its function is to detect zero pressure differential across the valve, thereby permitting it to open. The switch supplied by the valve manufacturer was too sensitive to pressure fluctuations. All these switches have now been replaced by much less sensitive snap action switches.

Because of design error, the gantry crane is unable to lift the transformer through its side leg as envisaged during specification preparation. Therefore extensive arrangements have to be made each time a transformer is moved.

CONTINUING CIVIL AND HYDRAULIC PROBLEMS

An unusual problem was noticed on the spherical valve of one unit. When the valve closed, leakage occurred into the scroll case, causing oscillation of the valve seal. Being in resonance with the penstock, the pressure wave caused the other valve seals oscillate with a period of three seconds. The temporary solution was to add a solenoid controlled water supply to maintain seal closure. The seal was utlimately replaced, at which time damage was found to be limited to the rubber D-ring seal strips between chamfers at the seal.

A minor detailing error occurred in the room where the water inlet to the strainers is housed. The floor drain is only 4" dia. while the inlet pipe to the strainers is 30" dia. A malfunction occurred resulting in a discharge which could not be evacuated fast enough to prevent a rise in the room water level. To close the inlet valve, the operator had to walk through a flooded room containing energized electrical panels. The solution has been to increase the drain size and to install emergency switches outside the room.

There is a history of surface sloughing and sliding of the slopes around the lower reservoir, particularly near the powerhouse access road. FERC is aware of this and has asked for monitoring and proposals for remedial works. The largest single movement occurred during a flood in 1984 when overnight a sudden increase in water level was recorded.

There has been some sedimentation in the lower reservoir operating range. There is limited inflow to the lower reservoir and almost none to the upper reservoir which is larger than the lower reservoir. There is no predictable way to fill the upper reservoir if it is drained. There are no gates on the penstock and it has never been drained. An outside company is going to perform an underwater inspection of the penstock, probably 25-50% of its length. The water conduit is lined with reinforced concrete except for the last 1780 feet at the powerhouse which is steel lined. There are drains which have shown virtually no change in flow since 1973. If the plant was built again the operators would insist on a gate for the penstock.

DESIGN COMMENTS

In discussion, a number of ideas for different ways of doing things (or things to avoid) arose.

- The staff felt that major weatherproof covers over outdoor cranes would be invaluable since most work is done in Spring and Fall.
- An engineer's model of the plant, or at least one bay of the plant prepared at the design stage, would have been invaluable to ensure working room during maintenance and to avoid difficulties in pipe routing etc.
- Ventilation in the scrollcase would improve the comfort of the personnel present for cavitation repairs.
- Transformers should always be specified FOB at site, not at factory, and should come as a unit train with impact recorders.
- It is important to get correct and clear equipment drawings, spare parts lists and templates since the severe service of pumped storage equipment makes spare parts important. Drawings allow the owner to gain an advantage by competitive bidding for replacement parts and modifications, and templates facilitate any repair of the hydraulic contours.

ELECTRIC POWER RESEARCH INSTITUTE
HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-4 - CABIN CREEK

VISIT DATE - 27 MAY 1986

OWNER: Public Service Company of Colorado

OWNER'S REPRESENTATIVES:

Frank Mathie - Plant Manager

EPRI REPRESENTATIVES:

B. E. Sadden - MKE - Civil Engineer
J. L. Carson - MKE - Mechanical Engineer

GENERAL AND PLANT DESCRIPTION

Cabin Creek is located about 35 miles west of Denver, Colorado. When it was commissioned in 1968, it was a milestone in pumped storage development. At that time it was one of the highest head plants in the world, operating at high altitude and high unit speed. The machines were among the biggest reversible units ever constructed. The upper reservoir is formed by a rockfill dam about 210 feet high and about 1500 feet long with a concrete face, while the lower dam is a 95-foot high earth and rockfill structure about 1200 feet long. The crest of the upper dam is 11,202 feet above sea level. The powerhouse is a semi-outdoor type reinforced concrete structure 145 feet long, 99 feet wide, and 100 feet high containing two Francis reversible units. The nameplate ratings of the units are:

	As Turbine	As Pump
Net Head	1190 ft	1230 ft
Output	160 MW	840 cfs
Speed	360 rpm	360 rpm

Starting of the units is by pony motors.

The units are serviced by an outdoor gantry crane of 90-ton capacity and an indoor bridge crane of 15-ton capacity. The water conduit consists of a 964-foot long sloping shaft with an internal diameter of 15 feet, a 1563-foot long horseshoe tunnel and 1530 feet of 12-foot diameter steel lined penstock.

The project was constructed between spring 1964 and spring 1967.

On the day of our visit, the plant was operating normally except that the staff were investigating some minor relay problems during starting sequences.

OPERATIONAL ASPECTS

Cabin Creek was originally built to be a peaking station but very quickly became a regulation station at low output (below 50 MW). At present, it is used mainly during a summer peak and a winter peak. The winter peak occurs December to January and the summer peak occurs when the air conditioning load gets high. Typical operation for a winter's day and depending on the electrical system load, is: pumping 12:00 p.m. till 7:00 a.m., generation from 7:00 a.m. to 10:00 a.m. at 60 MW, generation from 10:00 a.m. to 6:00 or 7:00 p.m. at 130 to 160 MW. Late in the afternoon the units would stop. The corresponding cycle for a summer peak is: pumping from 12:00 p.m. till 7:00 a.m., generating from 3:00 or 4:00 p.m. to 7:00 or 7:30 p.m. and on spinning reserve till midnight.

The units are rated at 160 MW each but during tests, they reach an output of 178 MW. The minimum load on the unit is limited to 60 MW due to vibration. Compressed air is injected at low load, using a different inlet point but the same compressors which are used for the tailwater depression system.

No problems have been associated with spinning reserve or synchronous condenser operation.

Dispatchers can control the load within set limits but they cannot control the voltage. The dispatchers can trip units via circuit breaker opening but cannot start units.

Units normally operate on block load, and rarely govern except in the case of power loss at another station.

Pumping is at constant gate opening, about 39%.

Braking is at 12 rpm (3.3%) speed. High pressure lift pumps are operated up to 80% speed.

Estimated availability of this station is as follows:

	1984	1985	1986
Availability of Unit A	91.41%	96.0%	93.7%
Availability of Unit B	91.47%	94.3%	97.0%

Operating Record For 1985

	Hours (Unit A)	Hours (Unit B)
Generating	399	460
Pumping	421	402
Synchronous Condenser Work	1347	1459

Downtime (not in operation) - 7940 hours.

Power 1985

	Unit A	Unit B
Generating	29,020 MWh	35,693 MWh
Pumping	52,411 MWh	47,352 MWh
Synchronous Condenser Work	4,819 MWh	5,607 MWh

The best yearly generating to pumping ratio so far has been 0.67 but this includes the synchronous condenser operation.

Operating times are as follows: starting - ten minutes for generating spin, ten minutes for generating, ten minutes for pumping using starting motors.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

Currently, outage for maintenance is programmed to be 27 days per year per unit. Three days are used in the spring, during which time each unit is inspected to determine exactly what will be done in the fall. In the fall, 24 days are programmed, although normally that 24-day period is not used.

Staffing for operation and maintenance includes one electrician, four mechanics, nine operators (that is, five shift operators and four ordinary operators), plus one supervisor. There are two operators on duty at all times. For major overhauls and some special items such as breakers a company construction crew is used.

The units have had a history of inconsistent operation as can be seen in other parts of this report. A major overhaul took place from June 21, 1979 to January 1982 prompted by the mechanical failure of one runner and cracking of the other, during which time the generator pole pieces, the runners and wicket gate bushings were changed. On one unit all wicket gates were replaced. The actual replacement work required one year but the outage lasted two years due to a delay of delivery of the runners. After the turbine failed, the turbine shaft was disconnected and the generator was used as a synchronous condenser until the overhaul actually started.

Cavitation damage is repaired on a two year cycle, though cavitation repair is rarely needed since the installation of stainless steel runners.

TURBINE PROBLEMS

Many cracks were noticed in the runners starting from the date of commissioning and the Unit A runner eventually failed, damaging the wicket gates. The runners were replaced in 1981 and 1982 with slightly modified stainless steel units, along with wicket gates on Unit A.

Upon startup, a problem with upthrust, similar to that at Taum Sauk, was experienced despite the modifications in unit design intended to prevent it. The problem was finally eliminated by the installation of a single balancing pipe connecting the head cover and bottom ring without automatic valving.

The original lower wearing rings failed within the first year after 420 hours of operation and the units were then operated for almost 20 years without them. When the runners were replaced, new lower wearing rings were made in three parts. Unfortunately, they had to be cut into four parts to enable installation. The lower wearing rings were originally designed with the inner ring stationary, but this caused runner unbalance. The new wearing rings have stationary rings, both inside and outside of the rotating ring. Bolts holding the wearing rings have been breaking, but the problem is being solved by the installation of new, larger bolts. Diffusers were put in the draft tubes and they seem to have reduced some of the vibration.

Unit B was having a guide bearing failures every six months, which required three days' repair each time. After the unit was rebuilt, the bearing failure has not recurred so the manager suspects that the problem was due to misalignment.

Vibration in the draft tube has resulted in leakage around the draft tube liner. The cracks were repaired with epoxy but some leakage still remained.

Many shear pin failures were experienced at first. The gates were adjusted and no shear pin failures have occurred since. Staff consider that the original turbine erector had probably not set the gates correctly.

Equalizing lines have been a problem. There was a lot of flow through the lines when the units were operated without the wearing rings. This resulted in cavitation failures of the equalizing lines, but the problem has been cured effectively with the new wearing rings.

GENERATOR PROBLEMS

There are two significant problems in the generator. The first one is that the generators have to be rebuilt every time that the turbine is dismantled because of a limitation of the crane capacity.

The second problem is that the iron in the stator starts slipping within the tolerances because of the laminations of the iron.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

Use of the lower reservoir is limited because of new flood rules. Between noon and 5:00 p.m., from June 1 through August 31, the surface elevation in the lower reservoir must not exceed 9990.0 feet.

Unit circuit breakers have performed relatively well but electronic circuit breaker head sensors are being installed to make sure that there is warning in case of a problem.

CONTINUING CIVIL AND HYDRAULIC PROBLEMS

Early problems with the tunnels involved the tunnel drain lines, which were installed on the outside of the steel lined portion of the tunnel that extends for a distance of 1530 feet inside the mountain. The drain lines were connected at the tunnel portal and manifolded to a deep underground gravity line routed around the powerhouse to a discharge below the low water level in the lower reservoir. This

arrangement prevented freezing and build up of ice at the point of discharge. A vent was installed where the drains left the mountain and entered the gravity line. Several months after startup, water began flowing from the vent pipe. On inspection, the gravity line was found to be plugged with calcium carbonate. After many attempts at cleaning, the line was finally opened by heavy and repeated treatments of hydrochloric acid. It would not remain open without continued frequent acid treatment. The line has been finally abandoned and drainage is now being handled through an open ditch.

The only other significant problem related to civil engineering has been the loss of aggregate from the tunnel lining. Because there is one tunnel and a bifurcation to two sphercial valves and no inlet gates when aggregate from the tunnel has been discharged through the turbine the upper reservoir has to be drained for tunnel inspection. It takes 10 days to drain the upper reservoir. This is mainly because they drain 100 feet in two hours, hold for 12 hours, then another 100 feet in two hours and hold for 12 hours.

There has been no major slope erosion on the reservoirs. When the upper reservoir was drained, the tracks of earthmoving equipment could still be seen on the floor. However, several small landslides occurred in the cut banks at various locations around the upper reservoir at the times of spring thaw and runoff. These have been corrected by flattening the slopes and installing underdrains of perforated redwood pipe.

Rock movement and snow slides have occurred in the early history of plant operation. For instance, a snow slide on the east side of the valley destroyed about 200 feet of fencing in the spring of 1969.

The downstream valve seals were scored, which was repaired by reversing the seal which was symmetrical.

The penstock to the upper reservoir can be filled by means of a fire pump to El. 10,300 ft. Water from the intake sump is used to fill to El. 11,059 ft. Then the unit pumps are used. They can also fill naturally in four to five days by a stream which flows into the upper reservoir.

The reservoir was overfilled once in the past, probably because of an operator error. Water overtopped the dam. There are two alarm systems installed now and the units are tripped automatically in case overfilling is imminent.

Early in the project operation, some of the transmission towers and take-off towers, adjacent to the powerhouse and on the lower dam, constructed on spread foundation on deep fill, experienced differential settlements of four to five inches between legs. As a result, some of the diagonal compression towers' members buckled. Corrective measures have been taken since.

COMMENTS AND IDEAS

Items which were brought up during the discussion if the plant were to be built today were the following:

- The plant should be designed for attended operation.
- It would be useful to have more covered storage, both indoors and out.
- Vibration and temperature detectors are necessary.
- Stainless steel runners would be more appropriate.
- Duplication of strainers for cooling water is a must.
- Duplication of compressors for spherical valves would be useful.
- The spherical valve oil system should have more storage capacity since the valve can only stroke twice before recharging of the system is required. The limited system capacity is restricting the plant on black start capability to only one attempt per unit at present.

The plant's personnel feel that the drawings provided by the equipment manufacturer are insufficient. However, it is recognized that manufacturers are reluctant to disclose their proprietary information. The importance of the owner receiving all drawings to allow for competitive bidding for replacement of spare was discussed.

PAPERS

1. Walker, R.F. and Hugo, R.V., "Pumped Hydro Peaking Displaced Steam Units," Electrical World, July 25, 1965, pp. 52-53.

2. Robertson, L.M., Kiesling, P.W., and Wasselkow, C., "High Altitude Pumped-Storage Plant to Develop 325 MW at 1,190 Foot Head," Electrical World, July 26, 1965, pp. 55-56 and 94.

3. Robertson, L.M., "The Design and Construction of Cabin Creek Pumped-Storage Hydroelectric Project," ASME/IEEE Joint Power Generation Conference, September 18-22, 1966, Paper 31, pp. 66-547.

4. Robertson, L.M., Burt, L.A., Eastom, F.W., Hubbard, C.W. Eyden, B., Howe, J., Dunaiski, R. and Johrde, P., "The Cabin Creek Pumped Storage Hydroelectric Project - Performance and Field Testing," Joint IEEE and ASME Meeting, Denver, Colorado, January 12, 1968.

5. Robertson, L.M., Burt, L.S., Eastom, F.W., Hubbard, C.W., Brennan, F.L., Fuller, J.F. and Johrde, P.S., "Electrical Design and Testing of Cabin Creek Pumped-Storage Hydroelectric Project, IEEE PA&S, Vol. 87, No. 3, March 1968, pp. 844-854.

6. Reichwein, L., "Cabin Creek Pumped Storage Hydroelectric Project - Operation and Maintenance," Hydraulic Power Committee, EEI, April 23-25, 1968.

7. Marks, J.A., "Cabin Creek Extends Frontiers of Pumped-Storage Technology," Electric Light and Power, October 1968, Vol. 46, pp. 75-78.

8. Hubbard, C.W., "Cabin Creek Pumped-Storage Project," Water Power, April 1969, pp. 129-134.

ELECTRIC POWER RESEARCH INSTITUTE
HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-5 - CARTERS DAM

VISIT DATE - 12 MARCH 1986

OWNER: U.S. Army Corps of Engineers

OWNER'S REPRESENTATIVES:

Curtis Love - Plant Superintendent
Charles E. Weassel - Power Plant Superintendent

EPRI REPRESENTATIVES:

B. E. Sadden - MKE - Civil Engineer
J. L. Carson - MKE - Mechanical Engineer
W. R. Moon - MKE - Electrical Engineer

GENERAL AND PLANT DESCRIPTION

The Carters Project is located on the Coosawattee River in Georgia near the town of Carters. The upper reservoir is formed by a 2053-foot long, 445-foot high rockfill and clay core dam and saddle dams, with a total length of 700 feet. A 210-foot long concrete gated spillway is located on the left abutment. The lower reservoir is formed by a 2900-foot long earth and rock dike and a 168-foot concrete gated weir approximately 6000 feet downstream.

The waterways connecting the two reservoirs include four 18-foot diameter, steel lined tunnels approximately 835 feet long, connecting four separate gated intake structures and an indoor type powerhouse. The powerhouse contains four Francis units, of which Units 3 and 4 are reversible, serviced by a 360-ton overhead bridge crane.

The powerhouse is about 361 feet long and 114 feet wide, including the draft tube deck. The nameplate ratings of each of the two reversible units are:

	As Turbine	As Pump
Net Head	345 ft	347 ft
Output	129 MW	4435 cfs
Speed	150 rpm	150 rpm

Construction of the plant began in 1962 and completed in 1975. Initial operation of the first pump-turbine was in 1977.

On the day of our visit, no special maintenance was being carried out. The staff was kind enough to demonstrate a pump start for us, which was somewhat complicated by a faulty brake release relay.

OPERATIONAL ASPECTS

Carters operates on a daily cycle, usually generating for two hours in the morning and two hours in the evening. Pumping is usually carried out from about 10:00 p.m. till 6:00 a.m. and on weekends. Typically, the pump turbines would operate 300 days per year. The units are block loaded by the dispatcher. The pump turbines are rarely used as synchronous condensors (less than three hours per year each) as must of the condensing is by the conventional units. Pump starting is back-to-back, semi-synchronous by using a starting unit at 80% speed as an isolated generator. The pumping unit starts as an induction motor until at approximately 50% speed the field is applied and the units synchronized. Starting current in held to 7800 A. Generation is rough in the range of 60 MW to 100 MW.

Pumping is carried out at "best efficiency" wicket gate position, per manufacturer's recommendations. The curves supplied have been confirmed by field tests.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

The operation of Carters is manned by one man per shift (five total). Three plants are controlled from Carters. Maintenance staff for the plant are limited to three electricians and three mechanics. There is a two-year cycle of basic maintenance. The inspection last for two weeks. If cavitation repairs are required, a three- to four-week period is required.

Annual summaries of operation from 1978 to 1985 reveal that availability of Unit 3 averaged 95.6%, while availability of Unit 4 averaged 97.65%, including planned outages and biennial inspections.

Recurring small problems that normally only require a few hours of maintenance included field ground relays, main bus, bearings, shear pins, etc.

TURBINE PROBLEMS

Major repairs were required on the reversible turbines (Units 3 and 4) due to failure of the bolts securing the cover plate the runner split on Unit 4. The plates, which were approximately 40 square inches and 1-1/2 inches thick, were held in place by 5/8-inch diameter cap screws and tack welded came completely loose on Unit 4. On each unit, all six covers were replaced and welded completely around their periphery, together with some plug welding. Relief holes were drilled in the top plates. These repairs took five months for Unit 3 and six months for Unit 4.

Another problem on the units is the priming time. It takes from 12 to 15 minutes to prime the pump, which is considered excessive. The staff have experimented with closing the runner band drain before and after priming, which affected the downthrust during priming but in both cases it was outside of the design criteria. It was felt that a pressure limit of 195 psi for wicket gate opening could be set lower and thus take into account lag time. A 160-psi limit lowered priming time and downthrust. Another solution considered was the conversion of the five-inch orifice in the equalizing line to a motorized valve to ensure an open line during priming. The manufacturer discussed all the problems and pointed out that the Carters runner was of an old design. Runners designed later are conical and contain air holes. No solution has been found to limit the priming time.

The original teflon square packing has been changed to molybdenum disulfide and pins added to prevent rotation.

The wicket gate adjusting link slips and the gates must be adjusted periodically.

The rubber distributor seals, which were secured by bolts wash out and require replacing.

GENERATOR PROBLEMS

Approximately 40% of the stator clamping bolts on the starting unit broke due to low frequency vibration during startup of the pumping unit.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

The major problem in ancillary equipment was the severe wear on the 230 kV switchyard circuit breakers. The original sequence of shutting down a pumping unit

involved opening the 230 kV circuit breaker at 25% to 28% gate opening. This required rejection of approx. 130 MW each time and thus required major repairs of contacts and baffles approx. every 450 operations (one year). Time for delivery and cost of parts made this a prohititive operational arrangement. Four scenarios were considered to resolve the problem, as follows:

1. Replace the circuit breakers with a different type breaker, such as a puffer breaker for which maintenance will not be required until after 5000 operations.

2. Insert a circuit interrupter in series with the breakers. The circuit breaker will still perform protective functions.

3. Attempt load rejection at a lower gate position to determine the optimum position for shutdown. The manufacturer of the oil circuit breaker indicated that a different shutdown mode may well produce worse abuse.

4. Use a generator to unload the pump turbine. However, this method was previously attempted on pumps at Mississippi Test Facility and was not successful.

After a thorough study, SF_6 puffer breakers were installed and are operating satisfactorily.

CONTINUING CIVIL AND HYDRAULIC PROBLEMS

There have been little or no problems with the civil aspects of the plant, but the trashracks at the lower reservoir cracked due to vibration. The shape of the leading and trailing edges was changed from round to a knife edge, which solved the problem.

PAPERS

1. Burdin, W.W., "General Design of the Carters Pumped Storage Project," Power Division, General ASCE Proceedings, Paper 7353, Vol. 96, PO3, June 1970.

ELECTRIC POWER RESEARCH INSTITUTE
HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-6 - CASTAIC

VISIT DATE - 16 DECEMBER 1985

OWNER: Los Angeles Department of Water & Power

OWNER'S REPRESENTATIVE:

Leon Brink - Plant Superintendent

EPRI REPRESENTATIVES:

B. E. Sadden - MKE - Civil Engineer
J. L. Carson - MKE - Mechanical Engineer
W. R. Moon - MKE - Electrical Engineer

GENERAL AND PLANT DESCRIPTION

On the visit day the plant was operating normally except for Unit 6, which was down with a thrust bearing failure. Unit 1 was out of service for a major overhaul.

Castaic Power Project is located on the west branch of the California Aqueduct about 22 miles from the northern limits of the City of Los Angeles. The capacity of the Aqueduct was enlarged to allow construction of the project. The forebay (upper reservoir) for the project is Pyramid Lake, formed by a 1080-foot long, 381-foot high dam. The lower reservoir is Castaic Lake, regulated by a small forebay installation called Elderberry. Elderberry forebay dam is 2000 feet long and 170 feet high, and by regulation allows variations in the level of Castaic Lake to be minimized. The two reservoirs are joined by the Angeles tunnel, which is 30 feet in diameter and 7.2 miles long, a 120-foot diameter by 400-foot high surge chamber and six steel penstocks. The powerhouse is an indoor type containing six reversible Francis units and synchronous generator-motors.

Nameplate rating of each unit is as follows:

	As Turbine	As Pump
Net Head	10 ft	1065 ft
Output	239 MW	2300 cfs
Speed	257 rpm	257 rpm

There is also one conventional unit of 50 MW capacity. The units can be isolated by 104-inch diameter spherical inlet valves and draft tube gates.

Initial operation was in 1973. Considerable rebuilding of the units has been necessary since then.

OPERATIONAL ASPECTS

Castaic operates in the normal morning and evening generating sequence, and night pumping if inexpensive power is available from the Northwest. Typically though, most of the time the units operate as synchronous condensers. During a typical day the plant may be generating for seven hours and operate as synchronous condensers for the rest of the time. When operating as a synchronous condenser, each unit requires 3-1/2 to 4 MW from the system. When pumping, units require 240 MW of power. Starting is back-to-back, using one unit as the starting generator. When generating, the units have certain restrictions because outputs between 80 and 150 MW involve rough operation, so this range is avoided. After repair on Unit 5, it was discovered that a range of operation of 125 MW to 175 MW was unacceptably rough, so this unit has further restrictions. When generating, the units are used for load regulation. Brakes are applied at 30 rpm.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

The units have had a history of significant problems, particularly with bearings and vibration, and there is, as yet, no scheduled yearly overhaul as such. However, the units, including the stator, are inspected thoroughly for one day on a six-week inspection cycle. This is a short time interval but they do hope to apply an organized maintenance schedule as soon as the vibration is kept under control. Maintenance is carried out by Water Department staff but paid for by the Power Department.

Eighteen weeks has been scheduled for each major outage, but it has usually taken nearly one year. Unit 1 has been down since January 1985.

TURBINE PROBLEMS

On Unit 1, the turbine valve leaked while the unit was in the synchronous condenser mode. The leaking water turned to steam, distorting the runner to such extent that it had to be replaced. Now, staff have installed temperature sensors (RTDs) in each thrust and guide bearing segment. Cavitation repairs are carried out every 18 months. No measurement is made but an estimated ten pounds of weld material is used each time. Wicket gates have experienced cavitation damage as well, which has been repaired with epoxy. New wicket gates have been installed in Units 5 and 6 and those on other units will be replaced in the next overhaul. Cavitation damage to the upper draft tube was also repaired using epoxy.

There have been some problems with the packing, and carbon rings are now being used on some units. There was difficulty depressing the water level in the draft tube. Staff attribute that to the problems with the packing. However, additional 120 psi compressors were installed. The wicket gate seals material was neoprene, but the seals are now being replaced with brass ones.

GENERATOR PROBLEMS

As mentioned above, there has been considerable downtime due to thrust bearing failure. The probable cause is a shaft misalignment which caused a vibration of 0.080 inches in the bearing bracket. Realignment of the 52-foot shaft has reduced this to 0.020 inches. The thrust bearings have been failing first and foremost, but some failures have occurred in the lower generator guide bearings. The shaft has been realigned optically and the thrust bearing support springs repositioned to equalize the bearing shoe support stiffness. Differences in spring stiffness resulted in up to 4,500-lb. loading difference between the shoes. After analysis and repositioning, the load differences between the shoes are down to 150 lbs. This has reduced the temperature variation between shoes from 18°C to 4°C. Each spring was analyzed and a computer program was written to select groups of springs and calculate their total stiffness. This selection was repeated again until the stiffness difference between the shoes was cut down to a reasonable amount. The positioning of the springs for each shoe was such as to start with the stiffest spring at the center of the shoe and spirally place springs with the least stiff springs of each group arranged at the periphery.

Staff feel that the optical alignment is much better than wire alignment. The shaft alignment involved cutting the mounting between the stator and its base plates, centering the stator over the turbine and rewelding it in place. On the last unit to be overhauled, elaborate care was taken and the shafts were aligned

within 51 microns. The net result is that this unit, which had the springs modified, has been operating for over a year without any bearing problem.

There have been many loose wedges on the stators. No winding failures occurred and very little corona damage. On the rotors, the field coils are being replaced due to failure of the windings and trouble with the spacers coming out.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

The circuit breakers need continuous service. The manufacturer has indicated that they are good for 2000 operations between servicing, but the operating staff are thinking of changing to SF_6 circuit breakers which seem more reliable.

There have been no failures of the switchyard 230-kV oil circuit breakers, but they do require constant inspection and overhaul. The breakers are rated for only 200 close-open operation beteween inspections. There are no problem with obtaining spare parts for the breakers, but the owner is looking to replace the OCBs with SF_6 circuit breakers.

CONTINUING CIVIL AND HYDRAULIC PROBLEMS

Civil and hydraulic problems have been limited to large deposits of mud in the lower reservoir as a result of a fairly extensive storm. The mud had to be taken out and dumped in a spoil heap. The outlet tower was constructed out-of-plumb. Attempts were made to install the gate guides plumb, but the gates are still not operating correctly and the operating mechanism does not have sufficient hoisting capacity.

COMMENTS

The staff consider that the most important lesson learned was that design criteria should be conservative. The machines should be constructed in a more substantial manner. They felt that the generator frame was not strong enough to cope with the excess vibration and the wear and tear of pumping and turbining. They also think it's a good idea to have a lathe, which could be used on the main shaft. The lathe has now been provided.

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HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-7 - FAIRFIELD

VISIT DATE - 8 JANUARY 1986

OWNER: South Carolina Gas & Electric

OWNER'S REPRESENTATIVES:

Sam Stockman	- Manager
Ed Robinson	- Maintenance Supervisor (not at plant during visit)

EPRI REPRESENTATIVES:

A. Ferreira	- EPRI	- Coordinator
B. E. Sadden	- MKE	- Civil Engineer
J. L. Carson	- MKE	- Mechanical Engineer
W. R. Moon	- MKE	- Electrical Engineer

GENERAL AND PLANT DESCRIPTION

Fairfield plant is located approximately 26 miles northwest of Columbia, South Carolina and is a classic example of a pumped storage facility in association with a nuclear plant. The upper reservoir (which also serves to provide cooling water for the nuclear facility) was formed by the construction of four dams, the largest of which is 5000 feet in length and 180 feet high. The lower reservoir is formed by the addition of gates to the 2000-foot long spillway of the Parr hydro facility.

The intake for the powerhouse is a concrete structure containing 127,000 cubic yards and is 350 feet long with four water passages. There are four 26-foot diameter steel penstocks that bifurcate at the powerhouse into eight 18-foot, 7-inch diameter penstocks. The powerhouse is 520 feet long, 150 feet wide and 108 feet high.

As part of South Carolina Electric & Gas Company's Plant Betterment Program, Fairfield was visited in December 1980 by a team of six consultants representing the original consulting engineers. The comprehensive report produced at that time was used as a basis for some of the discussion during our visit.

Fairfield contains eight reversible Francis units with individual wicket gate servomotors. Rating of each unit is as follows:

	As Turbine	As Pump
Max. Head	167 feet	173 feet
Min. Head	150 feet	158 feet
Output	75 MW (max. head)	4615 cfs (max. head)
Output	64 MW (min. head)	4985 cfs (min. head)
Speed	150 rpm	150 rpm

Initial operation was in 1978. On the day of our visit, no major maintenance was in progress.

OPERATIONAL ASPECTS

Operation is local with an operator and an attendant. Originally, the main mode of operation was block loading, with occasional speed governing. Now it is generally used as a peaking facility. It rarely operates as a synchronous condenser. Maximum possible generator output is 75 MW at maximum head, but normal operation is between 45 and 65 MW. Pumping is performed at the best gate position of 60% and requires 77 MW. Normal operation would involve generating from 8:00 a.m. till 11:00 a.m. and from 1:00 p.m. to 7:00 p.m. Pumping is performed from 11:00 p.m. to 6:00 a.m. with full storage recovery over the weekend. There is some restriction on the upper reservoir drawdown because of the nuclear plant cooling water intakes.

The power demand has dropped off since 1979 and 1980, when the units ran as part of the base load. During a typical month's operation (April 1986), 43,527 MWh was generated and 61,236 MWh consumed in pumping, for a pumping-generating ratio of 71%. Starting is at reduced voltage. High pressure bearing oil pumps are operated at unit speeds below 50%.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

An annual inspection is performed on two units at a time due to the need to drain the penstock which serves two units. The time required for this operation is two to three weeks and is determined by the amount of cavitation repair required in that time. Cavitation repair is carried out on an annual cycle.

Normal maintenance crew consists of two electricians, two instrument technicians, three mechanics and three other personnel. There is no roving crew, but if necessary, outside welders are brought in or borrowed from other plants. Field staff also have a six-man crew for civil and general work. The major overhauls, which are expected in three or four years, will be contracted out. At present, it appears that there will be a necessity to rewedge the generators in three to four years. At that time, the turbine runners will be removed and wearing rings replaced.

TURBINE PROBLEMS

Operation at 65% gate opening was maintained for one year when it was discovered that the wicket gates were fluttering. It was found that operation at 60% gate was much smoother, and pumping is now performed at that opening. The vibration had damaged the wicket gate bushings and all the gates were removed by the manufacturer, and new bushings installed along with quad ring seals and chevron packing replacing the original square packing. Greasing intervals were changed from six hours running time to two hours clock time. There are twenty wicket gates and ten stay vanes, and the worst wear occurred on the gates between stay vanes. Repair of two units took 12 weeks at two shifts per day.

There was also damage to the wicket gate upper seals because of upthrust. It seems that the original thrust collars were not strong enough to keep the gates down.

Runners are cast mild steel with stainless steel overlay.

After three years of operation, repair of cavitation damage required 600 lbs. of welding material, but the current rate is 40 lbs. of welding material per year for the cavitation damage repair.

There has been cavitation damage on the lower band and on the buckets. The distance between the bottom of the bucket and the bottom of the band is not uniform. Cavitation is occurring in the gap between the draft tube where this distance is small. For the runner repair, templates were made of the best runner buckets and these are being used to modify the others. There has been no cavitation in draft tube. Cavitation and cracking are occurring in the equalizing lines at the head cover connection and at welds where backing rings were used. The O&M staff propose examining the embedded equalizing lines with TV cameras.

Prior to 1982, during a hot summer, the bearing temperature remained constant for about eight hours after startup and then started rising. This corresponded to a sudden onset of vibration. A consultant from the manufacturer recommended raising the rotor and shaft 1/4 inch, the reasoning being that after the shaft warms up and expands, the gap at the bottom of the runner becomes so small that a pumping action is set up around the seals. Units 5, 6 and 7 have been modified. The pilot valves controlling the 20 individual servo units on the wicket gates all leak oil. A governor tank flapper valve also failed, prompting the pinning of all linkages.

Failure of the individual gate servomotors to synchronize gate closure has caused imbalance of load on the bearings and wiped the babbit. This has occurred on three machines. The individual servomotors leak and require excessive maintenance.

Shaft runout caused many packing box problems. All units have been changed to mechanical seals.

The non-pressure fairing in the draft tube access hatch fell off during operation due to vibration. All remaining fairings have been taken off since.

Draft tube access mandoor streamlining covers were torn off their supports by the turbulent water stream at the very beginning of unit operation. The plates were to present a smooth surface to the water flow and not as a water barrier between the draft tubes and the access mandoors. They have not been replaced.

GENERATOR PROBLEMS

Stator wedges have become loose. In some locations, the wedges have migrated out of the slots. The wedges are inspected annually and replaced as needed.

The corona activity in the stator windings is monitored with a Partial Discharge Analyzer system.

Unit 2 had a neutral coil failure in May 1987, resulting in extensive iron damage.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

The draft tube gates were designed to form a smooth hydraulic surface in the slots when raised. The draft tube turbulence caused them to bounce, and one eventually fell, closing one-half of the water passage. All gates are now stored above the water level.

The original oil skimmers in the plant drainage system did not work, and oil-absorbing floating bags are used in the sump, along with a small oil skimmer which was retrofitted.

The transformers for the static excitation system were undersized for synchronous condenser operation and overheated as a result. As a solution, fans were added. The original transformers, rated 500 kVA, were also PCB-filled and have now been replaced with 750 kVA dry type transformers.

The electrical system uses three power circuit breakers per unit: generator run, pump start, and pump run. In the past, these have been inspected and repaired every six months, but due to recent failures of the pump starting circuit breakers, the inspection and repairs will now be performed monthly.

There have been four failures of the pump start circuit breakers. Concurrently with two of these failures, there have been two failures of main power transformers.

All original Magna-Blast power circuit breakers are being converted to use vacuum interrupters.

The differential pressure switches across the trashrack were capillary type and were replaced with a "bubbler" type system because the original system used a closed diaphragm type system, which was very sensitive to temperature variation.

CONTINUING CIVIL AND HYDRAULIC PROBLEMS

The penstock expansion joints leak after dewatering and refilling, probably due to temperature variations while dewatered. In the majority of cases, the flow ceases later. The maintenance crew has tried to disassemble and repack two joints, but the effort required for this operation was extensive and cannot be further justified. Injection of sealing material into the packing area has been successful.

The paint on the draft tube gates did not bond correctly. Lack of protection has led to corrosion of the gates, which have had to be repainted.

Gratings over the intake vents to the penstock have been displaced because of the water ejected during load rejection. Grates are now mechanically fastened in the openings.

Gates have been somewhat of a problem. The upstream gates were hanging in the slot to streamline the flow. There was excessive gate vibration, so they had to be raised, requiring a modification to the raising mechanism. A similar phenomenon occurred at the downstream side of the unit, resulting in some damage to the gate. Excessive vibration of the suspended gates resulted in one gate falling. Since then, the gates have been raised and dogged.

Downstream gates had J-seals installed on the bottom of the gates. These failed and have been replaced with flat seals. There is no bypass on the upstream gate, and the gates have to be cracked to fill the penstock. The cracking of the gates has led to damage of the J-seals.

A well laid out powerhouse bears an evidence of shrinkage cracking at the floor, top deck and the east wall.

The supports for the generator form a circular concrete ring system consisting of a continuous bracket supported on a wall. The underside of the brackets and the inside face of the wall form the turbine pit below the generator. There are several vertical cracks that extend the full height of the ring wall. The cracks seem to be caused by concrete shrinkage.

There is an excessive amount of leakage through the powerhouse cracks, contraction joints and expansion joints, probably caused by incorrect waterstop installation. Many joints have been packed and grouted, which has reduced inflow.

The water leaking through the cracks on the operating floor of the auxiliary bay causes slipperiness and potential electrical problems inside the switchgear cabinets. Maintenance personnel have drained the switchgear bases by breaking through the grout pads, but they recommend using membrane material under the pads in the future.

Water is leaking onto the floor inside the generator housing of Units 3 and 5 through radial cracks in the wall. A core has been drilled eight inches into the crack, accumulating water, which is then pumped out.

The pump/turbine pit drains have become blocked. In some cases, the blockage must have occurred during construction because it is caused by concrete. Other drains are blocked with the calcium carbonate leached from the cracks in the concrete. Each turbine pit now has a submersible pump in the pit with a drain line running

across the floor to the nearest drain. Blocking of drains by concrete or calcium carbonate has occurred throughout the plant.

The pumps in the main drain sumps are adequately sized to handle seepage, but the water is prevented from reaching the sumps due to the clogged piping. A roto-rooter is periodically used to clean the drainage piping deposits. High pressure water blasting has proved to be more successful.

As a result of the seepage, the humidity within the plant is extremely high in the lower levels and causes condensation on some of the piping and equipment. Electrical equipment at the lower level has experienced numerous grounds and required considerable maintenance.

Another leakage problem mentioned by the operators occurs at the side of the translucent panels over the units. The flashing details are inadequate and, in one case, water leaked onto the top of the generator, causing a trip.

A small amount of an oil-like substance was oozing from the drains connected to the outside of the scroll cases. The scroll cases were coated with bituminous material above the springline so this may be the source of the problem. Drains were installed to eliminate any water buildup between the casing and the concrete.

EARTH DAMS

Piezometric measurements of high seepage pressures led to installation of relief wells at one dam and a rock berm at another dam, both to increase the factor of safety. Otherwise, all four dams have functioned well.

ELECTRIC POWER RESEARCH INSTITUTE
HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-8 - HELMS

VISIT DATE - 6 JANUARY 1988

OWNER: Pacific Gas & Electric Company (PG&E)

OWNER'S REPRESENTATIVES:

Bobby Mooneyham	- Superintendent
Greg Lemler	- Maintenance Supervisor

EPRI REPRESENTATIVES:

A. W. Borenstadt	- MKE - Project Manager
J. L. Carson	- MKE - Mechanical Engineer
W. R. Moon	- MKE - Electrical Engineer

GENERAL AND PLANT DESCRIPTION

Helms plant is located on the North Fork of the Kings River in the Sierra National Forest, approximately 50 miles east of Fresno, California.

The plant utilizes two existing reservoirs. The upper reservoir, Courtright Lake, is formed by a 304-foot high, 862-foot long rockfill dam with reinforced concrete facing. Construction was completed in 1958.

The lower reservoir, Wishon Lake, features a 290-foot high, 3330-foot long rockfill dam, also faced with reinforced concrete. Construction was completed in 1958.

The waterways include a concrete-lined tunnel 27 feet in diameter and approximately 15,000 feet long, with a short 22-foot diameter pipe 230 feet long crossing at Lost Canyon. The tunnel is followed by a 2200-foot long, concrete-lined penstock, also 27 feet in diameter, followed by three steel-lined, 12.5 to 8-foot diameter branches, each 700 feet long.

The draft tubes extensions are concrete-lined circular tunnels 15.5 feet in diameter, each 270 feet long, followed by a circular, concrete-lined tailrace tunnel 27 feet in diameter and 3797 feet long.

Hydraulic transients in the system are mitigated by surge tanks installed on the headrace and tailrace tunnels.

The powerhouse is located in an underground cavern 336 feet long, 83 feet wide and 144 feet high, containing three reversible units. A separate cavern contains ten single-phase transformers (one spare). Two 270-ton bridge cranes in the powerhouse can be used jointly by means of a coupling beam for total capacity of 525 tons. The powerhouse is accessed by a 30-foot wide, 25-foot high, 3700-foot long tunnel.

The switchyard can be reached from the powerhouse by an elevator located in an 18-foot diameter, 1053-foot high elevator shaft. The powerhouse cavern is supported with rock bolts and some shotcrete. The originally conceived unlined rock roof was retrofitted with a corrugated metal roof to protect equipment from dripping water.

Nameplate rating of each unit is as follows:

	As Turbine	As Pump
Net Head	1665 ft	1500 ft
Output	358 MW	2400 cfs
Speed	360 rpm	360 rpm

On the day of the visit, the plant was operating on spinning reserve.

OPERATIONAL ASPECTS

Helms was originally planned for unattended operation, but the operating experience indicated that it is not practical to contemplate such procedure at the plant of this size. However, PG&E is operating the plant using automatic control with operator observation.

Plant normally works on a weekly cycle with one generating and one pumping mode per day and pumping during the weekend.

The generating mode usually lasts 12 hours, from 7:00 a.m. to 7:00 or 8:00 p.m. and pumping mode about 5 to 6 hours, from 11:00 p.m. or midnight to 5:00 a.m.

Starting of the units is by means of a pony motor on each unit with one liquid rheostat serving all three units. It takes approximately seven minutes to spin the

unit from standstill to rated speed. The valve opening time is two minutes. Pumping can be started within 10 to 15 minutes of changeover. The starting power requirement is 30 MW for rotating and 70 MW when priming. In the generating mode, the unit can be brought to full load in 17 seconds after synchronization. All three units can be brought to full load of 1200 MW in under four minutes. The units are block-loaded to meet load requirements.

The plant is designed to operate as a synchronous condenser, but since PG&E does not require this service, the necessary electrical equipment was not installed. The units pump at 320 MW and 70% gate and generate between 0 and 402 MW. Brakes are applied at 15 rpm.

Operation is generally scheduled, but occasionally units have to pick up the load rejected by a failed unit in the system.

The operation and maintenance crew totals 28, as follows:

1	Superintendent
10	Operators (8 shift and 2 relief)
2	Electrical Machinists
2	Electricians
2	Electrical Technicians
2	Communication Technicians
2	Waterways Maintenance Workers
1	Hydro Engineer (position vacant)
1	Clerk
1	Automotive Mechanic
1	Maintenance Foreman
1	Operation Foreman
2	Helpers

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

In order to gain the operating experience and data on the rate of wear on the units, Unit 2 is operated more frequently than the other two.

All units undergo annual inspection lasting one week. The bearings and runner inspection and repair is scheduled at 3-year intervals. This inspection is estimated at five weeks using a crew of twenty-five from outside of the plant, with 6-day workweek, 10-hour shifts per day. No major disassembly is done. The inspection of the tunnels is scheduled at 5-year intervals. After four years of operation, the plant shows negligible wear on the runner and no wear anywhere else. The plant records availability of approximately 91%.

TURBINE PROBLEMS

Four of the head cover drain lines cracked due to vibration. The balancing lines had to be reinforced. The hydraulic operator for the draft tube mandoor does not provide sufficient operating force.

GENERATOR PROBLEMS

The major problem with the generator and, by virtue of its magnitude, the whole plant was the vibration of the unit. This vibration was due to the critical speed of the rotating elements coinciding with the operating speed and prevented proper operation of the plant. It was found that the coupling between the generator rotor and the stub shaft was not sufficiently rigid. The flange of the stub shaft was strengthened with gussets which, together with careful adjustment of the upper guide bearing clearances, raised the critical speed to an acceptable value and eliminated the vibration.

The support for the generator guide bearing pads is in the form of a box, which has a different stiffness at the sides than at the corners. It was necessary to compensate for the varying stiffness by varying the bearing clearances over each quadrant. Nevertheless, it is necessary to heat the bearings during shutdown. The thrust bearing pads are cooled by direct water circulation. During startup, the thermal distortion caused the bearing to fail. Controls for modulating the water flow were added, which solved the problem.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

There have been no significant problems with the ancillary mechanical and electrical systems and equipment.

CONTINUING CIVIL AND HYDRAULIC PROBLEMS

There have been remarkably few civil problems at Helms. Both reservoirs have stable banks, there is no silt movement in the waterways, and no rockfalls anywhere in the system. The walls of all excavated areas accessible to inspection are stable and free of cracks and spalling. This is primarily due to the excellent granite formation in which the plant is excavated. There is some leak into the plant works estimated at approximately five to six cfs, most of which is originating in the penstock plug area. Little leakage is evident in the powerhouse cavern. Considering that the powerhouse is located almost 300 feet below the lower reservoir level (and 2000 feet below the upper reservoir) the leak can be considered moderate. Some drains in the powerhouse occasionally become clogged with calcium carbonate

and have to be cleaned out. Since the plant cannot be drained by gravity, the unwatering system is of paramount importance for the plant safety. In order to save wear and tear on the main unwatering pumps and provide a failsafe back-up, a turbo-pump system driven by water from the penstock was developed, solving the leak handling problem rather elegantly. Since no electrical power is involved, the system is immune to moisture and spray, and can operate even when submerged. At the moment, only one of the two turbo-pump sets provided is sufficient to handle the plant leakage.

COMMENTS AND IDEAS

Asked what would they have done differently, had they had a chance to design the plant anew, the management indicated that, in general, they are very satisfied with the plant. In the minor category, they would provide more space in the control room, different closure of the draft tubes (probably wheeled gates), and a better quality in some auxiliary equipment.

ELECTRIC POWER RESEARCH INSTITUTE
HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-9 - HORSE MESA

VISIT DATE - 25 FEBRUARY 1986

OWNER: Salt River Power District

OWNER'S REPRESENTATIVES:

John Stafford - Operations Supervisor

EPRI REPRESENTATIVES:

J. L. Carson - MKE Mechanical Engineer
W. R. Moon - MKE Electrical Engineer

GENERAL AND PLANT DESCRIPTION

The Horse Mesa plant is located approximately thirty miles east of Phoenix, Arizona, and is owned and operated by the Salt River Power District. The pump-turbine powerhouse was added to the existing dam, which had a powerhouse containing three conventional units. The water is conveyed to the new powerhouse through a separate penstock.

The Horse Mesa pumped storage plant was originally a semi-outdoor powerhouse, but a separate sheet metal superstructure was added later. There are three conventional turbines and one pump-turbine installed. Starting is by a pony motor.

The pump-turbine is rated as follows:

	As Turbine	As Pump
Rated Head	246.5 ft	260.5 ft
Output	80 MW	3800 cfs
Speed	150 rpm	150 rpm

OPERATIONAL ASPECTS

The Horse Mesa plant typically generates during mornings and evenings. During the summer, generation is mostly during the evening. Pumping is generally from 10:00 p.m. until 7:00 a.m. and weekends. The unit is normally block loaded but sometimes is also used for speed regulation. Regulation duty is required more often at the Horse Mesa plant than at the Mormon Flat plant. The unit operates as a synchronous condenser for up to eight hours per day.

The pump turbine operates between 40 MW and 98 MW in the generating mode. Pumping is at a constant gate position.

The plant is manned three shifts a day during the week and two shifts a day on weekends. Normal control is from the dispatch center in Tempe.

MAINTENANCE, SCHEDULING, AVAILABILITY AND OUTAGES

The pump turbine is inspected annually, which takes five weeks. During this period, packing is replaced, circuit breakers are tested, and cavitation damage is repaired. The heavy maintenance is performed by a 16-man roving crew which covers six plants. No major repair was required so far.

PUMP-TURBINE PROBLEMS

The coupling between the pump-turbine and motor-generator slipped and damaged the radial drive pins. The coupling had to be remachined. An out-of-round seal caused a side load on the shaft and a bearing failure. There was cavitation damage in the head cover.

During the first repair, 1000 pounds of welding material was used on the runner where cavitation damage had occurred. Last year only ten pounds of welding material was used.

GENERATOR PROBLEMS

One coil failed in 1980, and during repair the stator was rewedged.

The pony motor - 10,000 hp wound rotor - initially had no upper bearing. During early starts, the electrical center of the rotor did not match the centerline of the unit and the rotor scraped the stator iron, resulting in extensive damage. A roller bearing was added and other changes made to correct the problem.

ANCILLARY MECHANICAL AND ELECTRICAL PROBLEMS

The draft tube trashracks had the same problem as at Mormon Flat. Although they did not fail completely, they still had to be replaced. The new design incorporated hold-downs and jacks.

The original transformer for the static exciter was PCB-filled and was replaced with a dry-type with the same kVA rating.

CONTINUING CIVIL AND HYDRAULIC PROBLEMS

The spray from the spillway, which is very close to the powerhouse, was collecting on the top deck in quantities sufficient to be a real problem. The original semi-outdoor powerhouse structure was modified by addition of the sheet metal superstructure.

COMMENTS AND IDEAS

Mr. Stafford stated that the lack of a powerhouse crane is a major liability and feels that a crane should always be included.

ELECTRIC POWER RESEARCH INSTITUTE
HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-10 - JOCASSEE

VISIT DATE - 6 JANUARY 1986

OWNER: Duke Power Company

OWNER'S REPRESENTATIVES:

Everett H. Gladden	- Area Hydro Manager, Keowee-Toxaway
Chas. E. McSwain	- Superintendent, Keowee-Toxaway
J. Michael Cloninger	- Superintendent, Bad Creek

EPRI REPRESENTATIVES:

A. Ferreira	- EPRI - Coordinator
B. E. Sadden	- MKE - Civil Engineer
J. L. Carson	- MKE - Mechanical Engineer
W. R. Moon	- MKE - Electrical Engineer

GENERAL AND PLANT DESCRIPTION

Jocassee plant is located 40 miles northwest of Greenville in Pickens County, South Carolina and is part of a major development called the Keowee-Toxaway Project, including hydro, pumped hydro and nuclear power generation.

The upper reservoir is formed by a 1,750 feet dam, 385 feet high and the lower reservoir is Lake Keowee formed by Keowee Dam and Little River Dam.

The reservoirs are connected by two tunnels, each of which bifurcate, supplying a total of four Francis type reversible pump turbines in a semi-outdoor powerhouse. There are no inlet valves, but each penstock inlet is controlled by a vertical circular gate. The rating of each turbine is:

	As Turbine	As Pump
Net Head	294 ft	294 ft
Output	170 MW	6200 cfs
Speed	120 rpm	120 rpm

Two units were put on line in December 1973 and Units 3 and 4 were put on line May 1, 1975. On the day that we visited, there was no major maintenance in progress.

OPERATIONAL ASPECTS

Jocassee was designed to be a peaking plant but is now also a base load carrying plant and is used for system frequency control. Pumping is usually carried out from 11:00 p.m. till 6:00 a.m. and over the weekend, and generation starts as early as 6:15 a.m. It is uncommon for the plant not to pump every day. Typically, an average use would be 60 hours of generating and 45 hours of pumping per week per unit. There is some natural inflow in the upper reservoir. Pumping-generating ratio is 1.28. The machines have been operated as synchronous condenser but it has had a negligible effect on the system. Operation is by two operators per shift.

Units are rated at 152.5 MW. However, they usually run in generation between 100 MW and 170 MW, which is within the limits of their overload rating. The lower limit of generation is about 100 MW.

In an attempt to lower the shaft runout, they have lowered the pressure at which they open the wicket gate. It has been changed from 148 psi to 112 psi on the pressure priming switch. At the same time, there was a proposal to modify the wicket gate opening speed but eventually the only change was in the pressure priming.

No compressed air is used and atmospheric air is admitted only during generation. The amount of atmospheric air is determined by the wicket gate opening.

The starting method for Unit 2 is reduced voltage. All other units utilize the semi-sync start method. All protected relays will shut down the pump automatically.

The maximum water level rate of rise in the upper reservoir is 2/10ths of a foot per hour.

Timing of units is unknown, but recently there was a change from four units pumping to four units generating, a 2080 MW difference in four-and-a-half minutes.

All units are operated as pumps about the same number of hours. The starting sequence is 4-3-1-2. No unit has failed.

Brakes are applied at 15% speed.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

Annual inspection of each unit is scheduled for five days, of which one to two days is unwatering and watering.

There is, however, a preventive maintenance program on a daily, weekly, biweekly basis, etc. The inspection is as stated above. There has been no major cavitation repair carried out annually. Cavitation repairs are performed only during one of the major outages. So far, several hundred pounds of weld material have been deposited on each runner.

It is expected that there will be a major repair scheduled in 1992 when complete disassembly of the unit will be required for wicket gate work.

Each time a unit has been disassembled, i.e., for the wearing ring repair in 1978 and for the baffle plate installation in 1982, it has taken six months.

TURBINE PROBLEMS

As stated above, the lower limit of the machine operation is set at 100 MW because of the vibration and excessive noise. The vibration was caused by the excessive flexing of the conical baffle in the discharge ring and the wicket gates. The wicket gate linkage pins were changed to stainless steel. Thrust bearing support was also stiffened. This was done on all four units and the result was a lowering of the lower limit of output to 80 MW. In 1978, there was an excessive runout of one unit and when the operators inspected it, they found the wearing rings loose. The attachment bolts had not been tightened to the proper torqued. The bolts were redesigned to allow for higher tightening torques.

While the above work was being carried out, it was discovered that the conical baffle in the discharge ring, attached with intermittent welds, was fractured. The top of this conical baffle plate was cut off and the section rewelded into a box section with continuous welds.

Leakage of grease out of the wicket gate bushings, which did not have seals, has been a problem. Quadrings were put in the lower and intermediate wicket gate bushings and O-rings under the top gate bushing.

No cavitation or breakage was noticed in the equalizing lines.

The turbine guide bearings were originally lined with sprayed-on babbit and have suffered from the wiping. All bearings have been replaced at least twice. Next time, the bearings will be replaced with cast babbit.

There have been a number of shear pin failures and some buckling of the linkage. This is probably due to improper torquing of the friction devices.

It should be noted that although these are split runner machines, but there has been no problems associated with that design. The original packing box was aluminum with a bronze lantern ring. The box corroded badly.

The brakes are normally operated by compressed air and are applied at 18 rpm. Hydraulic oil can be introduced into the braking lines so that the rotor may be jacked up. High pressure oil pump turnoff occurs at 72 rpm.

GENERATOR PROBLEMS

The generator guide bearing supports for one unit failed and many of the welds were fractured. There was a progressive fracturing around the bearing as each part was repaired. The failure was initiated by lack of resilience in the upper guide bearing support ring, which allowed the generator to move and overstress the lower bearing support structure.

All machines have been rewedged in the last few years and the wedges have been epoxied in place. The end turns of the stator windings had to be re-tied early. Rewinding has not been required on any unit.

The amortisseur winding connections between poles on the rotors had the flexible leaves breaking. A redesign of the connector so that the solder to connect the leaves to the end pieces is more uniform has cured the problem.

There have been a few small leaks from the generator bearings.

In the last year, there have been four leaks in the generator air coolers. There are no fans in the generator air coolers, but simple paddles on the rotor. It is thought by staff that the cause of the leaks is the cooler design.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

Major wear occurred in the 230 kV circuit breakers for synchronizing the units to the transmission system. It appears that the breakers were only good for 500

close-open operations, which means they had to be rebuilt every four to five months. Each rebuild takes four days. The original circuit breakers have been replaced with puffer type SF_6 breakers.

There have been an excessive number of failures of vertical reach, 230 kV pantograph (vertical reach) disconnect switches used for phase reversal. This was due to the large number of operations. In addition, temperature changes effected the closure. The switches have all been replaced with double-break, horizontal turning type.

Some transformers have been gassing and have been returned to the factory for repairs. It is the operators' opinion that the transformers are not structurally adequate.

CONTINUING CIVIL AND HYDRAULIC PROBLEMS

The main civil problems at Jocassee have been limited to water leakage. The tunnels were very leaky when the plant commenced operation and had to be regrouted immediately. Voids were found behind the lining at the top of the tunnel. These had to be repacked or corrected in 1983.

Both abutments of the dam have also shown leakage and some settlement. No remedial action has been taken but leakage has been intercepted and a number of flumes and a weir have been installed to effect long-term monitoring.

The powerhouse has also suffered very slight leakage at contraction joints between units. The leakage is confined to the joint and is not a major problem.

ELECTRIC POWER RESEARCH INSTITUTE
HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-11 - LEWISTON

VISIT DATE - 19 NOVEMBER 1985

OWNER: New York Power Authority (NYPA)

OWNER'S REPRESENTATIVES:

John D'Angelo	- Chief, Mechanical Maintenance
Edward Fitzgerald	- Resident Manager
Charles W. Grose	- Senior Project Engineer
Charles I. Lipsky	- Superintendent of Power (since transferred)
Howard G. Copeland	- Superintendent of Maintenance
Willis Binkley	- LPGP Mechanical Foreman

EPRI REPRESENTATIVES:

A. Ferreira	- EPRI	- Coordinator
B. E. Sadden	- MKE	- Civil Engineer
J. L. Carson	- MKE	- Mechanical Engineer
W. R. Moon	- MKE	- Electrical Engineer
J. Cogan	- MKE	- Geotechnical Engineer

GENERAL AND PLANT DESCRIPTION

The Lewiston pumped storage plant is a part of the complex on the American side of Niagara Falls. Construction of the plant began in September 1958 and ended in December 1962.

The lower reservoir for the scheme is the intake channel and forebay for the Robert Moses power plant and the upper reservoir is man-made with a continuous earth and rockfill embankment averaging 55 feet in height and 260 feet wide at the bottom. Total length of the dike is approximately 6-1/2 miles.

The plant is a semi-outdoor type about 974 feet long, 160 feet high and 240 feet wide and includes 12 units. The nameplate rating of each unit is:

	As Turbine	As Pump
Net Head	75 ft	85 ft
Output	21 MW	3,400 cfs
Speed	112.5 rpm	112.5 rpm

Penstock diameter varies between 18 and 24 feet.

The plant is serviced with a 150-ton gantry crane.

On the day of the visit, Unit 4 was dewatered for routine cavitation repair and the EPRI representatives were able to inspect these repairs. No other maintenance was underway at that time.

OPERATIONAL ASPECTS

Lewiston is not operated in the typical manner of a pumped storage plant. Operation is governed by the demands of the Robert Moses Niagara Power Plant at Niagara Falls, which is operated in accordance with a treaty between the USA and Canada.

This treaty, governing the use of the water that flows in the Niagara River, provides for guaranteed flows of 50,000 cfs over the falls during the daytime from November through April and 100,000 cfs during the daytime from April through October 31. During the night, flow of 50,000 cfs is maintained throughout the year. All other water is split 50:50 between Canada and the USA.

The Lewiston plant stores water during nighttime hours to provide flows of up to 50,000 cfs to the Robert Moses plant downstream during the day when high flows over the Niagara Falls must be maintained. The plant pumps during the night (approximately 10 p.m. - 7 a.m.) to store water for release during the day (typically 8 a.m. - 6 p.m.). Control of Niagara Falls flow is by the gates operated by Ontario Hydro. In general, the upper reservoir is pumped full during the weekend and, although pumping is carried out each night during the week, there is a gradual reduction of water level in the upper reservoir until Friday night.

The units are operated in the pump mode at best gate. In the gen mode, the desired total water outflow from the plant is normally achieved by committing the most efficient number of units and loading them at the optimum point for this flow. There is no load regulation. The units cannot be operated automatically as synchronous condensers. The average number of mode changes per day is two.

The units are normally base-loaded, computer-controlled on remote-auto from the Robert Moses Niagara Power Plant Control Room.

The rating of the generators is 20 MW, but they are consistently operated at 33 MW to 36 MW at a head of 75 feet. As pumps, the units are rated at 28 MW and are operated at 37 MW. Both operations are well above the ratings due to the higher upper reservoir level.

In the pumping mode the motors are started "across-the-line", which causes a 2% voltage drop on the station service. The circuit breaker is closed at 95% speed when the field is applied.

Overall plant efficiency is estimated to be 60%.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

Major disassembly of each unit takes 2-1/2 months and is carried out about once every eight years. The overhaul requires about 6000 man-hours and would typically include leveling of bearings, replacement of seals, etc. Each machine has been overhauled twice.

Inspection is carried out once every 24 months, at which time no major dismantling is required. If possible, this and other planned maintenance is carried out between November and January (tourist off season) when more water is usually available for the Robert Moses plant. Inspection usually takes 12 days and includes cavitation repair. Typically this might take 600 man-hours, of which 400 man-hours are spent on cavitation repair, which requires 350 to 500 pounds of weld material per unit. If a rewedging is carried out, total time is approximately 900 man-hours. NYPA considers that if no cavitation repair were required, this 18-month interval could be extended to 2-1/2 years and could be completed in five days.

As an aid to the machining of the rotor for seal clearances, NYPA has devised a rotating table using a crane pivot mechanism. They have also developed a method for machining the top of the draft tube liner.

A major reason for unscheduled outage is the breakage of wicket gate shear pins. They have experienced about four such occurrences per year, each taking one day to repair.

Before rewinding, using Class H insulation, an estimated 90% of failures were coil failures.

TURBINE PROBLEMS

Many of the turbine problems are related to the hydraulic problems described below under Civil and Hydraulic Problems.

The original 5-bucket wheels were replaced (after 15 years) by new 7-bucket wheels. The original wheels suffered from radial cracks in the vanes. New wheels have not cracked but appear to suffer more from cavitation. As noted above, typical cavitation repair is 350 to 500 pounds of weld material per 18 months plus 50 to 75 pounds in the draft tube. Repairs involve removal of cavitation damage by grinding, refilling with stainless steel, and then grinding smooth. In addition to other areas, cavitation always occurs at the edge of the stainless steel overlay, so the extent of the stainless steel overlay is constantly increasing.

Wicket gate journals have had problems with excessive wear. The wicket gate stems have been welded and remachined on site. The bearings are grease lubricated and NYPA studied their replacement by Teflon. It was decided to maintain the grease lubrication because of the effect of vibration on Teflon. Removal and replacement of the bearings is difficult because head cover removal is not easy.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

The medium-voltage unit circuit breakers and the phase reversing switches have had switching problems due to the large number of operations. NYPA has modified the operating mechanism to provide a back-up positive opening mechanism to each circuit breaker.

CIVIL AND HYDRAULIC PROBLEMS

The hydraulics of the Robert Moses power plant intake channel have resulted in unfortunate consequences at Lewiston. The intake channel was originally designed for the flow of approximately 80,000 cfs, but because the Robert Moses units operate at 176 to 180 MVA (as opposed to the rated 167 MVA), there is often a flow of 100,000 cfs through the intake. Head loss at 80,000 cfs flow is 11 feet, but at a flow of 100,000 cfs it is 25 feet, thus considerably reducing the submergence of the Lewiston units. This problem is exacerbated by the slight increase in the conduit length at the intake gate over the original design.

The conditions can be improved or worsened by the wind conditions on Lake Erie which may cause the lake level to rise eight to nine feet at the Niagara end. This increases overflow at Buffalo, increasing the flow into the diversion channel. On the other hand, when winds are down, diversion flows are reduced slightly. The result of the low channel water surface elevation is that cavitation is considerable and at times it is not possible to prime the pumps normally. They are then primed by allowing water to flow through slightly open wicket gates from the upper reservoir while initiating the starting sequence.

There is a tendency for north/south compression in the local bedrock (longitudinally) which seem to squeeze the draft tube slightly when the head cover is removed. This has been dealt with by grinding the head cover and machining the lower seal ring.

Some leakage into the plant galleries is occurring but not really sufficient to be classified as a problem.

A major change occurred during final design/construction which has had an influence on the units. A portion of the reservoir was to lie on the Tuscarora Indian Reservation and the tribe limited the total area to a figure less than the original design. The dike was therefore raised 13 feet to meet reservoir volume needs. This raised the operating head for the pump/turbine units. Evidently it was too late to modify the units, which therefore consistently operate above rated power.

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HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-12 - LUDINGTON

VISIT DATE - 29 MAY 1986

OWNER: Consumers Power Company (51%) and Detroit Edison Company (49%)

OWNER'S REPRESENTATIVES:

Richard F. Gerkowski - Plant Superintendent

EPRI REPRESENTATIVES:

B. E. Sadden - MKE - Civil Engineer
J. L. Carson - MKE - Mechanical Engineer
W. R. Moon - MKE - Electrical Engineer

GENERAL AND PLANT DESCRIPTION

Ludington plant is located on the shore of Lake Michigan, which forms the lower reservoir. The upper reservoir is formed entirely by an earthfill embankment some 5-1/2 miles long and 103 feet high, enclosing an area of 1.3 square miles. The reservoir embankment is completely lined with asphaltic concrete and the floor is lined with a clay blanket three to five feet thick. Water is conducted to the turbines through a reinforced concrete-gated inlet and six steel penstocks with a diameter of 28.5 feet, reducing to 24 feet.

The powerhouse contains six reversible Francis units, each rated as follows:

	As Turbine	As Pump
Max. Total Head	353 ft	372.5 ft
Output	460,000 hp	11,000 cfs at 305' head
Speed	112.5 rpm	112.5 rpm

Construction of the plant began in March 1969 and the first unit went operational in January 1973 and the sixth one in October 1973.

OPERATIONAL ASPECTS

The plant is dispatching from the Ann Arbor pool which is operated by Detroit Edison and Consumers Power. However, Ann Arbor calls Jackson, which is the Consumers Power dispatcher, who actually calls the plant by telephone to put the unit on line. The Ludington operator selects the unit and activates it. Minimum load per unit is 240 MW because of vibration. The maximum load is 325 MW. After the units are on line, the load is controlled by the Ann Arbor dispatcher. On rare occasion, the units are operated at a manual maximum load, which could be 345 MW. However, normally Ann Arbor changes the load in 4 MW increments but does not use the plant to govern speed. The units were operated on joint control previously, but now each one is controlled individually with all units usually at the same load.

Operation is on a weekly cycle. On Monday morning the operation would start with a full pond with the surface elevation at El. 942; Tuesday morning the pond would have dropped approximately four feet; Wednesday morning approximately another four feet, etc.; until Friday evening the pool level would probably be around El. 880. Minimum pool level is El. 875. Below El. 875, only two units can operate pumping or generating. Pumping is performed from 11:30 p.m. until 7:00 a.m. on weekdays. Not much pumping would be performed Friday night but Saturday night pumping would be continued until 10:00 or 11:00 a.m. Sunday morning. During the normal week, typical generation would be carried out from 7:00 a.m. until 2:00 p.m. and from 5:00 p.m. until 10:30 p.m. During hot periods there is extremely quick turnaround from generating to pumping and also sometimes there is more generation during the afternoon and night. Occasionally, Ludington is used to store energy purchased from Ontario at attractive prices.

The units can operate as synchronous condensers but this is only performed about once a year for a few hours. This would normally be on a holiday weekend. During the holiday weekends, voltage tends to go up because of the maintenance work on transmission lines or other modifications to the generating system. In this event the plant operates as synchronous condenser for a maximum of eight hours. The time is restricted by the turbine manufacturer because of overheating. Synchronous condenser operation power requirements are 20 MW in the pumping mode and 18 MW in the generating mode. Synchronous condenser operation with the tailwater depressed is started in both generation and pumping modes but they cannot go from generate to spin generate. Starting is back-to-back but Units 1 and 6 have pony motors.

The generating pumping ratio has been about 0.71.

Starting times for the units are quite good. Two units can be started at the same time in the generating mode and it takes one minute for auxiliaries, one minute to synchronize, and two minutes to full load, making a total of four minutes. The synchronous pump start takes eight minutes, including one minute to depress the tailwater. The pony motor start takes 12 minutes. Pumping is carried out at best gate position. This actually turns out to be 70% over most of the range but at the top 10 feet of the pool level, the gate backs down gradually to 60%.

Pumping cannot start when the upper reservoir is above El. 932. At low heads, the units pass vibration range quickly but at the very high heads, sometimes they cannot get through this condition. There is also an associated time which allows overopening of the gate for two minutes to calm the vibration down.

The target plant availability is 93% to 94% including overhauls. Over the past few years, the availability has varied between 92% and 97%. The bearing high pressure pumps are on whenever the unit is operating. Brakes are applied at 10% speed.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

The first major overhaul commenced in April 1987 and is due to last nine months. The tentative plan is rebuild one unit every other year.

Initially, each unit was taken down each year for inspection and partial dismantling. However, the interval was changed to 18 months. Plans are to change the inspection program to an interval of two years for each unit (three units per year). The time taken for each inspection time is four weeks per unit with 16 people on two shifts. The inspection is usually performed in the spring and the fall. Apart from the visual inspection and partial dismantling and cleaning, there is cavitation repair carried out and currently 200 pounds of welding material per unit per 18-month period is used.

Every few years the plant is shut down completely for five days and leakage through the reservoir lining is measured. Currently, one inch of water is lost in five days, an equivalent equivalent of 16 cfs.

During every other inspection, the coating on the inside of the penstock is inspected.

Staff that are available are: 12 maintenance workers; 12 operators; three supervisors; one engineer; one superintendent; three technicians; one stockkeeper; one janitorial and one clerical person.

For inspection or overhaul outage, an additional four to twelve personnel are employed. Availability is 93.4% including planned outage.

TURBINE PROBLEMS

Generally the turbines have performed very well, although there were problems with the lower rotating wearing rings. The bolts holding the wearing rings on five units failed in one year. It is believed that this happened because of the heavy vibration lasting a minute or so during each pump start. It has happened on all machines and the solution has been to increase the wearing ring gap.

The welds securing the covers over the runner parting flanges failed, which required cutting four holes in the head cover in order to gain access for rewelding.

Equalizing lines have cavitated within the concrete. Orifices have been placed in the lines close to the draft tube. The embedded pipe replacement was difficult since it required jackhammering.

Some cavitation damage has been noticed on the stay vanes and on the wicket gates. The utility is experimenting with epoxy coating on the stay vanes.

GENERATOR PROBLEMS

There was a thrust bearing failure on Unit 1 on 24 June 1985, which was the first since the failure during commissioning in 1972. It is assumed that there has been some failure of the babbit due to stress concentration around the dovetail corners. The corners have been rounded to avoid future failure.

All generators have been rewedged. There has been little corona damage but the most serious problem has been a fire on the bus ring joints of Unit 1 in 1977. The maintenance staff assumed that thermal effects have loosened the bolts on the bus ring joints, thereby increasing resistance and eventually causing the fire. The number of bolts on all joints was increased from 12 to 24 bolts on Unit 1 and the other units changed to silver brazed joints. The heat tapes were also installed on the joints.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

In the opinion of the operating staff, ancillary equipment has also performed very well. Circuit breakers are the in-line isolated phase bus type manufactured by Brown-Boveri. Originally these were to have a major overhaul every 1000 operations. However, after 1000 operations the circuit breakers were in good working order. After 2000 operations, they were examined again and found to be in satisfactory condition. Finally, they have been overhauled after 3000 operations and the proposed schedule now is to carry out a major overhaul every 3000 operations. Initially there were some problems with the improper timing of the switch components, resulting in contact burning, and with control adjustment and vibration of internal parts, resulting in cracking of piping. However, these problems were resolved and resulted in the current satisfactory circuit breakers performance.

The main transformers are single-phase. One spare transformer is also provided. The transformers proved to be troublesome. A bushing has failed on one, there have been oil leaks, and three transformers were gassing badly. For the above reasons, single transformers have been changed out five times during the plant's operation. It takes one and half to two days to change a single transformer.

In the early years of operation, permissive controls tended to fail during semi-automatic pump start. The failures were related to burned out relays, dirty relay contacts, inoperative flow devices and improper operation of protective relaying. Delay to pumping starts were the only result; there was no damage to machinery.

There are 16 brake shoes on each unit and the brakes were set to engage at 15% speed but created substantial dust. Brake setting was lowered to 10% speed and they stay on constantly without pulsing. There has been no replacement of brake shoes in 13 years of operation.

CONTINUING CIVIL AND HYDRAULIC PROBLEMS

The civil works associated with the upper reservoir are rather special because the reservoir and penstocks are situated on sand. These features have been covered in many papers. There have been two particular incidents of failure there. The asphalt at the intake, bulged and eventually ruptured. A repair was effected, but the buldging recurred so an 18-point well system was installed, penetrating the asphalt at that point. At present, the well point system is pumped at a rate of 200 gallons per week.

While the above repair was being carried out, a shear failure was discovered in another part of the lining. Upon investigation, calcareous sand normally underlaying the lining was found to be missing from below that area. The sand was replaced and repatched.

There are 195 drainage pumps around the reservoir. Pump 4 comes on once a week and operates for about 2 hours and 12 minutes.

In addition to leakage through the liner, there are a substantial number of measuring wells and some pumping wells around the downstream toe of the embankment. In all, there are 41 pumping wells and 400 measuring wells. These have been installed gradually from 1973 to 1976, depending on the groundwater elevations measured.

The lake breakwater has survived very well and only once some stone had to be replaced after a major 1974 storm.

A minor problem is icing of the lower trashracks. This has happened nine times in 13 years. It happened for three nights in a row in 1984, but it did not happen in 1985. The icing was traced to frazil ice build-up on the trashrack. When this condition occurs the operators switch from pumping to generation, which usually removes the ice from the trashracks, after which pumping can be resumed. There is no ice problem in the upper reservoir where there are no trashracks.

COMMENTS AND IDEAS

The plant personnel would definitely have a stainless steel runner. They also believe that much better weather protection is required for unit dismantling. There are four months of the year when staff are reluctant to take machines apart because of inclement weather. They suggest weather protection around the gantry crane similar to that at Lewiston. In addition, they feel that better soundproofing would improve working conditions within the plant. Finally, they consider that a spare set of thrust bearings and a substantial number of wicket gates are required. They have four wicket gates but the plant superintendent thinks they should either have 20 or none at all. They have six spare wearing rings and two sets of guide bearings, but are not sure about how useful they are.

ELECTRIC POWER RESEARCH INSTITUTE
HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-13 - MORMON FLAT

VISIT DATE - 25 FEBRUARY 1986

OWNER: Salt River Power District

OWNER'S REPRESENTATIVES:

John Stafford - Operations Supervisor

EPRI REPRESENTATIVES:

J. L. Carson - MKE Mechanical Engineer
W. R. Moon - MKE Electrical Engineer

GENERAL AND PLANT DESCRIPTION

The Mormon Flat plant is located approximately thirty miles east of Phoenix, Arizona, and is owned and operated by the Salt River Power District. The pump-turbine powerhouse was added to the existing dam, which had a powerhouse containing a single conventional unit. The water is conveyed to the new powerhouse through a separate penstock.

The Mormon Flat pumped storage plant is an outdoor powerhouse containing one 54-MW pump-turbine. The plant is remotely controlled. Starting as a pump is at half voltage.

OPERATIONAL ASPECTS

The pump-turbine is rated as follows:

	As Turbine	As Pump
Rated head	129 ft	143 ft
Output	42 MW	3600 cfs
Speed	138.5 rpm	138.5 cfs

Mormon Flat typically generates mornings and evenings, with little morning generation during the summer. Pumping is from 10:00 p.m. till 7:00 a.m. and weekends. Generation is normally with block loading, but the plant does some speed regulation. The plant operates as a synchronous condenser up to eight hours per day. The pump-turbine operates as a generator at an output below 10 MW and between 30 and 44 MW. The plant is manned during the day shift only. Normal operation of the plant is by remote control from Tempe, where six operators control six plants.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

The pump-turbine is inspected annually, which takes five weeks. During this period, the packing is replaced, circuit breakers are tested, and cavitation damage is repaired. The heavy maintenance is performed by a roving crew of 16 personnel, including eight mechanics and four electricians. This crew maintains six plants.

The unit was dismantled in 1978 to repair a wearing ring, that had fallen off, and partially rewind the generator. The generator was completely rewound in 1981.

TURBINE PROBLEMS

In 1978 a wearing ring came off, requiring an overhaul of the unit. There has been galvanic corrosion of the mild steel runner adjacent to the stainless steel overlay. Belzona (a two-part thermosetting plastic) with a Couchen coating is being used for repair. During the first repair, 1000 pounds of welding material was required to repair cavitation damage, but only ten pounds of welding materials were required last year.

GENERATOR PROBLEMS

In 1978, one stator coil failed. This damaged four other coils and some stator iron laminations as well. To repair this and corona damage on the high-voltage end of other windings, one-third of the coils were replaced. In 1981 another coil failed and the stator was completely rewound. Prior to these events, the unit was running at 125°C (although the manufacturer would not acknowledge this). After the rewinding and minor changes to the cooling system, the unit runs at 85°C.

ANCILLARY MECHANICAL AND ELECTRICAL PROBLEMS

The draft tube trashracks failed and had to be replaced. They were not held securely in their slots and were damaged by the shaking action. The trashracks were redesigned and provided with hold-downs and jacks.

The original transformer for the static exciter was PCB-filled and has been replaced with a dry-type one with the same kVA rating.

COMMENTS AND IDEAS

Mr. Stafford stated that a crane should be installed at all powerhouses. The lack of a crane and the difficult access to the powerhouse makes removal of the rotor during an overhaul very difficult.

ELECTRIC POWER RESEARCH INSTITUTE
HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-14 - MT. ELBERT

VISIT DATE - 28 MAY 1986

OWNER: U.S. Bureau of Reclamation

OWNER'S REPRESENTATIVES:

Ross Mooney - Facility Manager
Barry Bartlette - Foreman

EPRI REPRESENTATIVES:

B. E. Sadden - MKE - Civil Engineer
J. L. Carson - MKE - Mechanical Engineer
W. R. Moon - MKE - Electrical Engineer

GENERAL AND PLANT DESCRIPTION

The Mt. Elbert Plant was built as part of the Frying Pan Arkansas Project about 15 miles southwest of Leadville in Lake County, Colorado.

The project forms on-line storage in the transfer of water from the catchment of the Frying Pan River to the Arkansas River. Runoff water is conducted from Turquoise Lake, through a 90-inch diameter, 10.5 mile conduit to the Mt. Elbert forebay and artificial upper reservoir for the scheme. The lower reservoir is Twin Lakes formed by a dam 55 feet high and 3140 feet long.

This plant is indoor, containing two Francis turbines without shut-off valves. Units 1 and 2 were supplied by two different manufacturers. One unit entered service in 1981 and one in 1984. Prior to installation, the machines had been stored for a long period. In addition, each of the units rotates in a different direction. Consequently, the only parts which are common to the two units are the reversing switches, unit circuit breakers and reactors. Each of the two units is rated as follows:

	As Turbine	As Pump
Net Head	442 ft	405 ft
Output	100 MW	3200 cfs
Speed	180 rpm	180 rpm

OPERATIONAL ASPECTS

The Western Area Power Administration (WAPA) in Loveland, CO, originally dispatched this plant as part of the Frying Pan Arkansas development. Now this plant is dispatched from a USBR control center, but effectively dispatched from WAPA. Generally, generation is controlled from WAPA but the only control they actually have is load control. Starting and stopping the units is performed at the plant but there is an uprating in progress on these controls. Starting in the generating mode is manual; automation is planned.

The plant is not fully utilized because of the low power demand. Only one unit is used at a time in most cases. A typical 24-hour cycle is from 11:00 p.m. to 7:00 a.m. pumping with one unit, from 8:00 a.m. to about 10:00 p.m. generating with one unit.

The lower reservoir is 10 times as large as the upper reservoir and the plant operators feel that if the upper reservoir were larger, they could utilize the plant more.

There is up to 400 cfs of inflow into the upper reservoir. The inflow is enough to keep one unit generating at full load for three hours per day during runoff periods.

Starting in the pumping mode is semi-automatic by means of static converters. Auxiliaries have to be started first and then the air depression system operated manually. Then an automatic starting sequence which finally closes the unit breaker. Loading is done manually.

The limits of operation for Unit 1 is from 25 MW to 106 MW, Unit 2 can operate from 10 MW to 100 MW. However, for Unit 2 the range from 50 to 60 MW is rough. The wicket gate position during pumping is controlled manually for best efficiency. There is an automatic system but it does not operate well.

The plant can run as a synchronous condenser in the pumping direction only. However, at low generation they can load VARs to a point (90 MVAR) where they are performing almost as a synchronous condenser.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

The Bureau normally runs a new unit for one year, or about 3000 hours, and then performs a thorough inspection. This inspection does not include the removal of the major parts but does include a general dismantling of the auxiliaries. At the time of this teardown, both units needed wedge replacement and Unit 1 had had corona damage. It was found that Unit 2 wedges hadn't been installed properly. The coils were loose but the wedges too tight.

Annual maintenance usually consists of visual inspection of the stator and rotor, pole voltage drop test and megger test, a visual inspection of all mechanical items, cleaning, and pipe and valve inspection. The turbine undergoes a visual inspection of the runner and measurement of wicket gate clearances following the Bureau's maintenance manual. Turbine bearings are drained and oil filtered every year, mainly because of condensation. Normal annual maintenance is scheduled for 30 days per unit. This year, however, the inspection required 14 days for one unit and it is expected that no more time will be necessary. Staffing consists of five operators, including one foreman, which mans the plant 24 hours a day. There are also two mechanics, three electricians, one utility man, one general maintenance man, one laborer, one foreman, two electronics technicians, one electrical engineer, and two secretarial personnel plus five other persons on civil works. As of June 1, 1986, they have the responsibility for one other power station. During major maintenance, people are brought from other parts of the Fryingpan-Arkansas project, as needed.

As for the major future maintenance, overhaul will be carried out as the annual inspection indicates. The plant has scheduled a 10-year rewind already.

TURBINE PROBLEMS

The most noticeable problem seemed to occur with Unit 1. The gate operating ring cracked for a particularly interesting reason. There was a 1-1/2 to 3 Hz vibration at the turbine being picked up by the linear variable displacement transformers in the electronic governors resulting in oscillations in the gate mechanism. This caused fatigue cracking of the gate operating ring upstand. Reinforcing plates were welded on the upstand and an electronic filter was installed in the governor to eliminate the vibration feedback. This measure has solved the problem.

The rubber gate seal on Unit 2 was torn during the initial operation but the tear did not progress. The bronze seal on Unit 1 is wire drawing.

In addition, leakage on Unit 1 gates was excessive. The lower bushings and the thrust collars were replaced and O-rings were installed on the bushings, after the unit had run for less than one year. Wicket gates were corroded even though they were stainless and were chemically treated.

The problem of the gate operating ring did not appear on Unit 2 because the ring is stronger.

The bolts holding the shaft seal on Unit 2 backed out, releasing the O-ring and the turbine pit was flooded.

The depression system, which operates at 125 psi, originally had proportional control systems for controlling depressed water levels. (Each unit has separate controls to a central system.) The control system was ineffective and was changed to a simple on-off system, with a dead band, using ultrasonic sensors.

GENERATOR PROBLEMS

Brakes originally came on at 25% speed, although there are dynamic brakes as part of the static starting equipment. Now the brakes have been adjusted to come on at about 12.5 rpm. Even so, there is still a lot of dust during breaking, but because of wicket gate leakage, breaking is imperative.

Times for starting are: generation four and half to five minutes (the record is three minutes for a good operator); pumping 12 to 15 minutes.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

There are two major problems regarding ancillary equipment. The first one is related to the static starting. The static starting equipment was the first made of the size required. It was shipped prewired and the erection engineer, working without a sufficient support, had to make about 150 field logic changes which were needed for the equipment to work. There are still some problems remaining and the operators have found that it is difficult to troubleshoot this hardwired system. The design has a cycloconverter and a static start. Initially the cycloconverter gives a small 'kick' to the stator but the design had no feedback to inform the cycloconverter whether the initial movement of the rotor was in the correct direction.

Another problem on the static starter was that the unit was built specifically by the manufacturer for their own machine thus requiring a number of modifications for the other unit. Among the other problems have been a destructive failure of the cycloconverter and a problem with spikes in the PTs, resulting in a vibration which bent some of the pins in the bearing spider.

The operators feel that by using a programmable controller in conjunction with the static starting, it will be possible to modify the system and get it working properly.

The dash pots brass sleeves on the unit circuit breakers are badly scored and the manufacturer recommended to rectify this problem. Even the replacement sleeves are out of round. Unit 2, for instance, had a failure during the ground-fault acceptance test. Breakers are rated at 11.5 kV and are probably derated for altitude. There is some delaminations on the exit to the arc chute.

CONTINUING CIVIL AND HYDRAULIC PROBLEMS

Unit 2 trashracks failed because the pulsating draft tube pressures. Pumping has been suspended until the new trashracks are installed.

The initial filling of the upper reservoir resulted in much leakage, which was repaired at a cost of $20 million. The entire bottom of the upper reservoir was covered with a plastic liner. The reservoir has not been drained since then and there is no way to get the water out of the upper reservoir if the units are shut down.

The stoplogs at the tailrace have no gantry crane so a mobile crane must be contracted and brought to the site every time a gate has to be lifted. This is extremely inconvenient since the crane takes a day to get to the site, and powerhouse flooding could not be prevented in the event of excessive leakage. As an example, when the shaft seal leaked and the turbine pit was flooded, it took one and a half days for the mobile crane to arrive at the site.

The plant does not have an emergency diesel generator to allow for a black start or for running the sump pump.

COMMENTS AND IDEAS

The plant operators would definitely have a stoplog gantry crane if they were doing this job again. An emergency generator would be needed and they highly recommend

that both pump/turbine units be identical. As far as the spares are concerned, they recommend that any spare that takes longer than 30 days to procure should be stored, with the exception of a runner and some other major items. A typical spares list would include spare air coolers, wearing rings, bearing pads, wicket gate bushings, shaft seal and spare cards for the electronic devices.

There are some leaks in the floor which only occurred when Unit 2 was started. The cracks have probably developed because of the soil foundation and movement of the plant.

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HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-15 - MUDDY RUN

VISIT DATE - 5 DECEMBER 1985

OWNER: Philadelphia Electric Company

OWNER'S REPRESENTATIVES:

Ernest G. Spey	- Superintendent
Les Baker	- Plant Engineer
Bill Langan*	- Assistant Superintendent
A. J. Weigand*	- Manager, Fossil & Hydro
G. MacNichol*	- System Economics

* Not at plant during visit.

EPRI REPRESENTATIVES:

A. Ferreira	- EPRI	- Coordinator
B. E. Sadden	- MKE	- Civil Engineer
J. L. Carson	- MKE	- Mechanical Engineer
W. R. Moon	- MKE	- Electrical Engineer
J. Cogan	- MKE	- Geotechnical Engineer

GENERAL AND PLANT DESCRIPTION

Muddy Run plant is located on the Susquehanna River in Lancaster County, Pennsylvania. The upper reservoir is formed by a 280-foot high earth and rockfill dam.

The lower reservoir is formed by an existing dam in the Susquehanna River.

The waterways include a concrete lined headrace canal, four separate gated circular intakes, four 24-1/2-foot diameter tunnels 400 feet long and four 24-1/2-foot diameter shafts 320 feet long. These bifurcate into eight steel lined penstocks 500 feet long and 14-feet in diameter.

The powerhouse is a semi-outdoor type 600 feet long, 140 feet wide and 80 feet high containing eight units. Nameplate rating of each unit is as follows:

	As Turbine	As Pump
Net Head	353 ft	427 ft
Output	110 MW	2610 cfs
Speed	180 rpm	180 rpm

On the visit day the plant was operating normally during a period of low river flow.

OPERATIONAL ASPECTS

Muddy Run was originally planned to be unattended, operated remotely from Conowingo. Operation is remote but the plant is attended around the clock by two operators.

Normal daily operation is to generate morning, afternoon and sometimes evenings, five days a week. Pumping is carried out with all the units every night seven days a week, usually 11:30 p.m. approximately to 6:00 a.m. They estimate, on average, six mode changes per day, but it may be from four to eight.

Normally, they generate 1,200,000 MWh per year and the pumping to generation ratio is about 1.42.

Muddy Run is not used as a synchronous condenser, although there is the capability to do so (it is an expensive feature for their system).

Operation is mainly scheduled, though occasionally they have to pick up the load rejected by a failing steam unit. The machines are used for system regulation.

Units are available for generating between 40 MW and 100 MW, which represents 40% to 100% of rated output. Below 40 MW they run very roughly and efficiency also drops.

During pumping the machines draw 116 MW. Pumping is undertaken at gate opening of 55%, which is a compromise between efficiency, power and roughness. It is less than the gate opening for peak efficiency. No smoothing air is used in operation. It is only used during pump starting and stopping. The staff consider that the machines are running relatively smoothly as pumps.

Upon discussion of operating restrictions, the staff stated that the maximum discharge for all units is 24,000 cfs, which is insignificant compared with a 50-year or 100-year flood on the lower reservoir. For instance, during hurricane Agnes

(which resulted in a flood with a recurrence period of 50 years), 1,017,000 cfs flowed down the river. The average river flow is 36,000 cfs.

As far as overfilling the upper reservoir is concerned, there is a sequential normal pump shutdown every three minutes when the level gets to El. 520.0. This is checked over the weekend by the dispatchers who often fill the reservoir up as much as possible by allowing the automatic shutdown sequence to be initiated. At El. 520.0, there is a trip of all units in an emergency shutdown sequence.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

Inspections are performed every two years on the pump turbines taking four weeks, checking for cavitation damage, cracks, wicket gate seals, deterioration, etc. With respect to the generator/motor, the inspection interval is four years, which has included removing the rotors. The inspection includes an assessment of wedges, corona leakage, etc. Major overhauls have been carried out as follows:

- Units 7 & 8 - 1983
- Units 5 & 6 - 1984
- Units 3 & 4 - 1985
- Units 1 & 2 - 1986

These are performed in pairs because of the penstock configuration. The staff have noticed a (stationwide) improvement of 4% in efficiency after the overhauls.

Maintenance is normally carried out by about four to five men assigned to Muddy Run from the Conowinga station. In addition, the company has set up a 15-man mobile turbine group, a mobile electrical group, and a mobile boiler group (who do the welding) for major maintenance. Turbine runners have been sent to the manufacturer for repair at major overhauls.

TURBINE PROBLEMS

A major problem with the turbine has been the formation of cracks at the outside diameter of the runner bucket. There are usually two to three cracks four to six inches long per runner per inspection. On six occasions, major pieces of the runner have fallen off.

Wearing rings have been replaced, reducing the clearances from 0.200 in. to 0.060 in. Before replacement, the equalizing lines were cavitating and cracks were appearing at the first horizontal elbow. Flexible pipes were tried, and then

replaced by standard forged pipe. Finally, stainless steel-lined pipe was used. Embedded pipe has always looked intact (by visual inspection). Since seal replacement there have been no problems of cavitation in the equalizing lines.

Before overhaul, the high wearing ring leakage caused increased thrust and thrust bearing wear or failure, particularly in Units 5 and 7.

There has been substantial cavitation damage in the draft tube liner just below the runner. The affected area has been replaced on three units.

There is cavitation damage on the runner itself. The maintenance staff has a set of templates and whenever they're doing cavitation repair, they check the runner contours and try to reshape it to the original contours.

The staff feel that the wicket gate seals could be better. Chevron packing in the bushings has been excellent. The lower gate bushings have been dry but the staff has been installing quad rings to improve lubrication in the lower bushings.

The wicket gates were vibrating, and at the manufacturer's recommendation, the trailing edges were shortened by six inches.

GENERATOR PROBLEMS

The generator has been a major item of maintenance and the staff feel that the generator frame design could have been better. The stator frame bolts are welded to the structural frame and break repeatedly. Also, they feel there needs to be a better design on the wedges and tighter side filler in the slots.

After seven years a number of ground faults occurred, coils were cut out and additional protective relays installed because of increasing coil failures.

The stators have all been rewound after 8 to 12 years of operation. Windings have dropped down and bad insulation damage was evident. Some vibration occurred and, on Unit 4, core hold-down bolts failed. On the 4-year schedule, the rotors are removed, all windings are tested, wedges replaced, as needed, using expansion spacers. There are no plans to rewind the stators or any other major modifications at this time.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

Unit circuit breakers are given a general inspection every 500 close-open operating cycles with normal replacement of contacts and other parts subject to wear.

CONTINUING CIVIL AND HYDRAULIC PROBLEMS

There have been relatively few problems with the civil works on Muddy Run. Drains and monitoring wells in and around the dam are monitored as required by FERC. The headrace canal has developed some problems. It is lined with concrete and has developed some cracks in the canal liner. Each year the canal water level is lowered and sometimes a contractor is called in to repair the lining. This work takes one week, and during that period, the whole plant is unavailable for use. There is some silting in the intake canal, probably three to four feet. The gate has a sill about four feet high and the silt has reached the sill level of the gate. The staff do not plan to lower the upper reservoir in the foreseeable future.

There has been no extensive maintenance on the trashracks apart from the repair of the cracking due to the Von Karman effect. This required installation of bracing on the large trashrack. The penstocks are inspected during the bi-annual outage, including the bifurcations. No problems are reported.

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HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-16 - NORTHFIELD MOUNTAIN

VISIT DATE - 23 NOVEMBER 1985

OWNER: Northeast Utilities

OWNER'S REPRESENTATIVES:

Paul Gamache	- Plant Superintendent (not at plant during visit)
Al Russ	- Assistant Superintendent
Art Sumner	- Maintenance Supervisor

EPRI REPRESENTATIVES:

A. Ferreira	- EPRI	- Coordinator
B. E. Sadden	- MKE	- Civil Engineer
J. L. Carson	- MKE	- Mechanical Engineer
W. R. Moon	- MKE	- Electrical Engineer
J. Cogan	- MKE	- Geotechnical Engineer

GENERAL AND DESCRIPTION

The Northfield plant is an underground powerhouse containing four Francis type pump turbines and synchronous motor generators rated at 250 MW generating at a head of 745 feet.

They have a nameplate rating as follows:

	As Turbine	As Pump
Net Head	745 ft	1000 ft
Output	391 MW	3850 cfs
Speed	300 rpm	300 rpm

Initial operation of the first unit commenced in November 1972 and the other three units went commercial in 1973.

On the visit day the plant was operating normally; no major maintenance was in progress. One of the investigation team, Mr. A. Ferreira, was the Project Manager

for the planning, design and construction of Northfield and is well acquainted with a number of aspects of the plant's history.

OPERATIONAL ASPECTS

The station is manned 24 hours a day by a staff of 15 operations people and 17 maintenance people. Control is effected in the plant control room but dispatched from the Connecticut Valley Power Exchange (CONVEX), a satellite dispatch office of the New England Dispatch Exchange (NEPEX).

Normal operation of the plant often includes two generation periods starting about 7:00 a.m. to 8:00 a.m. and ending about 8:00 p.m. to 10:00 p.m. each day. Pumping overnight is normally from 11:00 p.m. to 6:00 p.m. The original use of the plant was mainly under block loading but increasingly the plant is being used for load following and system reverse operation.

There can be as many as eight mode changes per day but four is more normal.

The generating to pumping ratio was 0.71, having dropped from 0.76 due largely to mechanical wear on the turbine components and to some extent because of load following. The current (1987) generating to pumping ratio is 0.75 following completion of major overhaul on three of the four units. The increase steams principally from restoring runner clearances to original dimensions.

Units are normally loaded from 125 MW to 250 MW. The lower restriction is because of rough operation with resultant shaft runout.

Pumping is performed at best efficiency with a gate setting of 57%.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

Maintenance is scheduled every 18 months and normally takes 16 to 17 calendar days. The maintenance always commences on a Monday to allow the weekend pumping to be completed. The original schedule was three weeks maintenance per year. During each maintenance period cavitation repair is performed which represents 60 man days work, and is the controlling factor in the downtime. Repair is performed with 30 to 50 pounds of 308 welding wire per unit (at $7 per pound). If the cavitation damage extends to base metal, 309 rod is used. In addition maintenance staff have tried Haynes 25 (at $50 per pound) which is much more erosion resistant to cavitation. It has been used extensively in the lower fillets. MIG wire application is

used rather than welding rod. Advantages of using wire are a reduction in the amount of slag and easier use by less experienced welders.

Major overhaul has been performed after 12 years. It was scheduled to take 24 weeks but was completed in 18 weeks. Future major overhauls will be scheduled for 18 weeks at 10-year intervals. The basis on which the decision to overhaul was taken was the impact of excessive seal clearance on unit efficiency. Another influence in determination of when to overhaul a unit was the generating/pumping ratio, though the staff acknowledges that changes in operational regimen also influences the ratio to some degree.

TURBINE PROBLEMS

The primary cause of forced outage has been the fracture of equalizer lines at the head cover. Also some of these lines exhibit perforation at the embedded elbows. This perforation has been evident by the inflow of "drainage" water from the concrete during overhaul and observations by use of a remote robot TV camera. Grouting of the surrounding concrete has been attempted in these areas. Cracks in the lines are occurring every 8 to 12 months on Unit 2. It is possible that cavitation at the elbows may be responsible. The staff theorizes that vortices in the draft tube may be inducing pressure fluctuations in the equalizer lines. At the head cover, this effect is magnified by the "washer" effect of the runner which has webs at the top, leading to pipe fractures at the head cover. However, these fractures may be heavily vibration related.

There has been vibration of units, particularly of Unit 2. This is the unit which staff say has a bent shaft. Balancing has been carried out, mainly in the generator, but Unit 2 had weight added to the washer.

Careful rebalancing has reduced downthrust and lowered thrust bearing temperatures.

Cavitation damage to runners is being repaired without templates, but the staff would recommend obtaining them from the manufacturer. In fact, during the next cavitation damage repair, staff will use templates prepared on the basis of those blades exhibiting the least cavitation damage.

Water passages on the runners have been coated with epoxy during recent major overhauls.

Some runners are coated. No. 4 and No. 2 are coated with a two-part polymer epoxy (polyamide). No. 3 and No. 1 are coated with polyvinyl ester paint. To date, the epoxy polyamide is 90% in place.

The wicket gates have been damaged by corrision, cracking and cavitation. Cracking has occurred in the high stress areas at the top and bottom of the gates. There is also some erosion damage evident, which may have started the cavitation. New stainless steel wicket gates have been installed on Units 1, 2 and 3. As a short term measure, they have been coated with epoxy. The new gates will have improved fillets in the area that is now cracked. Unit 4 gates were weld-repaired at the cracks, stress-relieved, and coated with epoxy. To date, these areas have not exhibited any further signs of cracking. The gates had a tendency to raise and rub the upper facing plate. This problem appears to have been solved by eliminating the adjusting nut in the thrust car and using a fixed shim pack for overall gate adjustment.

GENERATOR PROBLEMS

There has been one major overhaul on Unit 4 generator in 12 years of operation. Units 1, 2 and 3 were completely rewedged in 1975 and have been rewedged again during the recent major overhaul. Otherwise, there have been no other major problems.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

Unit circuit breakers require frequent maintenance, about semi-annually. Spare parts have been a problem. Northfield has been cooperating with Blenheim-Gilboa, who have the same breakers, to the benefit of both parties by interchanging parts.

Transformers are located underground, behind concrete blast walls. However, they may be lifted with the main powerhouse crane and transported out of the powerhouse should major repairs be necessary.

CONTINUING CIVIL AND HYDRAULIC PROBLEMS

The powerhouse is relatively small, which results in somewhat difficult maintenance. For instance, the runner cannot be turned over in the powerhouse and must be brought out of the access tunnel for this action. At the ground level outside the access tunnel, there are larger storage sheds and workshops to help offset the small powerhouse size.

Silt has not been a problem in the upper reservoir even though flow in the lower reservoir (river) is silty during spring flooding. In 1979, the heavy siltation

deposited in the intake channel was drawn into the tunnels during upper reservoir dewatering. Removal of silt from the tunnels was difficult and tedious. This occurred during fast drawdown at low levels. In 1984, the later stages of drawdown were at a much slower rate and the problem did not recur.

The powerhouse flooding, which occurred during plant pre-commercial testing, has been dealt with in other papers. Modifications to the hydraulic circuitry for the valve seals have been made to preclude a repetition of the inadvertent valve seal opening.

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CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-17 - RACCOON MOUNTAIN

VISIT DATE - 11 MARCH 1986

OWNER: Tennessee Valley Authority (TVA)

OWNER'S REPRESENTATIVES:

Gil Lindsay	- Plant Manager
Bill Dintsch	- Maintenance Supervisor
Dewey Rudder	- Asst. Plant Manager

EPRI REPRESENTATIVES:

B. E. Sadden	- MKE - Civil Engineer
J. L. Carson	- MKE - Mechanical Engineer
W. R. Moon	- MKE - Electrical Engineer

GENERAL AND PLANT DESCRIPTION

The Raccoon Mountain Pumped Storage Plant is located in the Tennessee River Gorge approximately six miles west of Chattanooga, Tennessee. The upper reservoir, located on top of Raccoon Mountain, is formed by an 8500 feet long rockfill dam 230 feet high. The existing Nickajack Reservoir is used for the lower pool. There is almost no inflow to the upper reservoir.

The water is conducted to the turbines through a concrete ungated intake structure in the upper reservoir located above the single 35 feet diameter shaft. There is a 1000-foot horizontal high pressure tunnel that splits into four steel-lined penstocks.

The powerhouse is an underground cavern 72 feet wide, 165 feet high and 490 feet long, containing four reversible Francis turbines protected by spherical valves. Each unit is rated as follows:

	As Turbine	As Pump
Net Head	1020 ft	1000 ft
Output	391.5 MW	3850 cfs
Speed	300 rpm	300 rpm

The four draft tubes are linked to a common underground surge chamber and then to a single discharge tunnel leading into the Nickajack reservoir. A cofferdam protects the river from the development of dangerous currents and possible bank erosion. A relatively unusual feature of the project is the location of the switchyard near the upper reservoir, necessitating the construction of a long cable shaft which is also used for visitors access.

The visitors facilities afford excellent views of the upper facilities and the powerhouse interior. Initial operation of the facility was in May 1978 and at the time the pump turbines were the largest ever built. On the day of our visit no major maintenance was in progress.

OPERATIONAL ASPECTS

Raccoon Mountain normally operates with a unit output of 425 MW. During summer, the output is somewhat reduced because of generator stator temperature considerations. Minimum load is 300 MW because of vibration of the turbine together with cavitation problems at lower loads. A vibration monitoring system has been installed. The units are normally block-loaded, although they are capable of speed governing. Pumping is performed at the best efficiency with the gate position set manually according to a chart. Based on maximum capacity of the pool, it is possible to generate for up to 20 hours and pump for 27 hours. Typically, generation is performed in the morning and afternoon, and sometimes also for an evening peak, while pumping is continued overnight and on weekends. This schedule, however is not regularly maintained. The units can operates as synchronous condensers. Tests for the synchronomous condensers operation have been performed but the plant has never been used in that mode. A typical number of starts per year would be 2000.

Times quoted for the operations are as follows:

Standstill to full load generation	:	1-1/2 to 2-1/2 minutes
Standstill to pumping	:	7-1/2 minutes
Pumping to full load generation	:	5-1/2 minutes

Mechanical breaking is achieved at 2% divided by 3% speed. The reason for not braking at any higher speed is the noise, the resulting brake maintenance and the dust generated.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

The difficulties in preparing the machines for operation has resulted in a delayed entry into a programmed standard inspection period. Most likely, the runner will be inspected every year and the rest of equipment every other year. However, at present they operate 5,000 to 6,000 hours between inspections for cavitation damage. The unit circuit breakers can be operated for 2,000 cycles before inspection. They actually operate 400 to 500 times per year. The inspection of the waterways is programmed every five years. O&M crews consist of 35 persons, including 14 operators (three per shift) and 21 others. Major maintenance is done by TVA personnel rotating through the TVA system. There have been major problems with Raccoon Mountain machines. Gil Lindsay surmises that the original vibration was probably due to an alignment problem. The major improvement was achieved by re-aligning the shaft. Among the many remedies attempted it is felt that the one that helped was dismantling the unit, and reassembling and checking the alignment. Thrust bearings performed satisfactorily on the machine, with a single failure due to human error.

The station was designed for unmanned operation. However, the plant is manned but the operations room is very small. Therefore, a trailer had been parked in one of the access tunnels to serve as offices for the staff. Now, a permanent office building has been constructed just outside of the entrance to the main access tunnel.

TURBINE PROBLEMS

All of the original turbine guide bearings, including the spare, failed. The original sprayed-on babbit bearings were replaced by poured babbit bearings and no more failures have occurred. Dowels between the wicket gate levers and stems came loose and the dowels have been replaced. The pins in the gate rings have teflon bearings and wear occurred in the pin holes. The original pins on the gate rings have been replaced by stainless steel pins on Units 2 and 4 and nickel-plated pins on Unit 2. There is considerable leakage past the wicket gate seals. This condition made it impossible to achieve the 400 psi spiral case pressure that was envisioned by the designers as desirable before opening the service seal relief valve. The relief valves are now routinely opened with the spiral case pressure as low as 275 psi. The seals on the wicket gates are brass with rubber cushions.

Measurements indicate that the instllation was not done properly and that original clearances above and below the wicket gates were incorrect. In addition, there was uplift under the wicket gate shaft from water getting into the lower bearing. There are no O-rings and there are no drains under the bearings. Unit 3 has been retrofitted with O-rings that have been installed on the wicket gate stems. They will be installed on the other three units when the opportunity arises. At first, because of upward pressure, the wicket gates became stuck at 3% gate opening. This condition was corrected with locking rings at the gate's thrust collars. It was found that grease washed out of the wicket gate bearings within two or three minutes operating the units. Now, greasing is carried out almost continuously while the units are operating rather than every eight hours, which was the original plan.

So far, there have been five pump/turbine wearing rings lost. A complete dismantling of the units is required for a permanent repair. This happened on Units 2, 3 and 4. TVA is not as yet in a position to program a complete overhaul. The turbine pit gravity drains of the unit are inadequate. Electric pumps have been installed in the head covers to handle the excess leakage.

GENERATOR PROBLEMS

Both the generator rotor and the stator are water-cooled and this system has caused only minor problems. The plant manager would describe the system as marginal simply because of the need to restrict the load because of temperature. The generator design restricts the actual temperature to 80°C. At the time of the visit, there was a leak in the stator cooling. There is an automatic shutdown on a sudden large leak, but in this case the leakage of about 8 gpm was not sufficient to trip the unit. Shutdown in this case was based on electrical faults. The actual leakage that occurred was 25 gallons in more than three minutes, which didn't trigger the shutdown. New instruments have been installed and adjusted to initiate a unit shutdown when a leakage rate of 2 gpm occurs. Brush life is excellent. Oil vapors from the guide bearing deposit on the brushes and there is a need to clean the collector rings every week. Some ring damage occurred before the seriousness of the problem was realized.

The Unit 4 generator shaft cracked at the bearing skirt. The oil pan riser was installed incorrectly and rubbed on the shaft, causing it to fail.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

All the downstream seals have been replaced on the spherical valves, but the upstream seals still leak at a rate of 1,100 gpm. The maintenance seals are used as

well as service seals when unwatering the scroll case. Only the downstream seals are closed during normal operation. Because of the maintenance seal leaks, a method of injecting horse manure into the valve through the bypass line has been developed, which temporarily seals the leaks.

A serious condition which resulted from the high vibration levels of Unit 1 was the loosening and/or shearing of 9 out of the 16 bolts on the flange holding the bypass pipe in place. The failure was very nearly catastrophic since the pipe was under penstock pressure at the time.

The plant is fitted with dynamic braking, but the breaking is generally avoided until the units have coasted down to one to two percent speed, then the mechanical brakes are applied. The reason for not braking at any higher speed is brakes operation noise and consequent maintenance.

The switchyard has been a problem, mainly the current transformers. Explosive failures have occurred in 1978 (three units), 1983 (three units), and 1985, a total of nine failures. Each explosion is extremely damaging to the nearby equipment. There is no known cause of the explosions, but the staff now monitors the power factor tap of the bushings, and it is believed that in 1985, nine failures were prevented. Current transformers coming out of service now are scrapped. There is a new program for installation of SF_6 current transformers, which is scheduled for the fall of 1987. Eighty percent of the work in the switchyard is on current transformers. The circuit breakers have performed satisfactorily. They are mounted separately on pedestals. Most current transformers failures have been during a period of no load in late summer, on weekends, or nights. The manufacturer has suggested that the original failures were due to arcing during motor operating and disconnecting. No explanations was offered for the later failures.

> NOTE: Along with TVA's research into the cause of CT failures, Westinghouse research has uncovered strong evidence that paraffin base insulating oil may be the cause of the CT failures.

Unit circuit breakers have an interrupter and an isolator. The interrupters are rebuilt every 2000 operations and the isolators every 4000 operations. Generally, parts for rebuild cost approximately $85,000.

There has been gassing on two transformers. Transformer 3 has been inspected and degassed, but no cause for gassing was found. It is now gassing again.

CONTINUING CIVIL AND HYDRAULIC PROBLEMS

Generally the civil features of Raccoon Mountain project have been performing satisfactorily. There is a minor leakage between the concrete and the bottom ring in one unit. In addition, there has been some minor leakage from the surge chamber into an access tunnel. Very little rock spalling was observed in the underground works, possibly 1/4 of a truckload per year. The measuring extensometers have not shown any major movement.

Penstock inspection has revealed no problems but there has been some silting in the upper reservoir. In 1984, the reservoir was routinely unwatered and when a scroll case door was opened, the scroll case was half full of mud. The river forming the lower reservoir clearly does carry silt which is being carried up into the upper reservoir. At this stage, the upper reservoir is flushed twice a year by very fast drawdown of the pool.

COMMENTS

The operators stated emphatically that the unit step-up transformers should not go underground. They also think that siltation preventing measures should be provided in the design, i.e., lower intake velocities. Also, manufacturers should always include optical alignment with the erection of the machines.

ELECTRIC POWER RESEARCH INSTITUTE
HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-18 - SALINA

VISIT DATE - 6 MAY 1986

OWNER: Grand River Dam Authority

OWNER'S REPRESENTATIVES:

Keeling McGaughey - Asst. General (not at plant during visit)
Charlie Bowling - Manager of Operations

EPRI REPRESENTATIVES:

B. E. Sadden - MKE - Civil Engineer
W. R. Moon - MKE - Electrical Engineer

GENERAL AMD PLANT DESCRIPTION

Salina Pumped Storage Scheme is located in Mayes County, Oklahoma, and is an aboveground, indoor powerhouse. The upper reservoir is formed by a dam 2300 feet long and 200 feet high. An 1800-foot long headrace canal, lined with concrete, conducts water to the concrete intake works and to six steel penstocks. The powerhouse contains six reversible Francis units, each rated as follows:

	As Turbine	As Pump
Head	225 ft	245 ft
Output	44.7 MW	2100 cfs
Speed	171.4 rpm	171.4 rpm

The lower reservoir, formed by a dam 1494 feet long and 90 feet high, is located on the Lower Grand River.

Provision has been made for an extension to the powerhouse for six more units, including blank inlets at the intake structure, and full excavation for the penstocks. The existing units were installed in two phases in 1968 and 1971. On the day of our visit, no maintenance was in progress.

OPERATIONAL ASPECTS

Normal operation at this station is by remote control from the Kerr Dam Control Center which operates the whole Grand River Dam Authority system. The plant is coordinated with the coal-fired units operation. Generally in summer, the generation begins at 8:00 a.m. and shuts down at approximately 11:00 a.m. and in late afternoon and early evening there is a second generation period. Pumping is carried out all night. Sometimes no generation is required and generally is spring and fall there is less use of the plant. Usually not more than one unit is generating at that time. The Grand River Dam Authority sells power to municipal, REA and other utilities, as well as to factories, but they do not supply power to residential consumers. The units can operate as synchronous condensers but that is not currently part of their operating criteria, as other plants on the system can do this more readily. The units are block loaded with a minimum load of 20 MW and a maximum load of approximately 48 MW. The units 'bang about a bit' operating below 20 MW. This vibration is probably general in nature rather than caused by the cavitation. The operators generally try to keep the operating time on each machine equal.

In spring, the plant often operates as a peaking plant. All units share the load equally during peak generation. This typically happens in the spring and fall, but its use in other seasons is increasing. Pumping-generation ratios are between 60% and 70%, depending on the amount of peaking duty the plant is required to provide. The plant availability is very high because there have been few forced outages.

Operating start up times for the units are as follows: pumping (full voltage across the line start) - 35 to 40 seconds to full speed and synchronization and then a further one minute to take the load; generation - two minutes on line if the butterfly valve has to be opened, 45 seconds if the butterfly valve is already open.

There have been times when all six units of the station have gone from zero load to full load in five minutes.

The different starting times, depending on butterfly valves being open, are caused by the fact that all auxiliary equipment is operating, and the butterfly valve is left open for 30 minutes after the unit is shutdown. The auxiliary equipment includes the high pressure oil pumps, cooling water system and brakes.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

There are seven persons plus a supervisor to operate and maintain the plant and every man can operate the plant if necessary. The crew is only at the plant on a day shift. The plant is unattended on nights and weekends. On weekends and holidays one man comes in to check the machines for malfunctions. It is seldom necessary to draw staff from other plants. Even during a major maintenance, the regular crew do the work. All plant equipment is carefully surveyed, as a first order of the day each morning, prior to starting the routine maintenance work. Should any problems be encountered, an immediate repair would be initiated.

One unit is taken out of service each spring for maintenance and another unit is taken out of service each fall. Thus each unit receives a major overhaul every three years. During this time, the following work is completed: the rotor is removed; the shaft is realigned; all bearings are inspected and their settings checked; all electrical equipment is cleaned and inspected; cavitation repair is performed; the wicket gates seals are repacked; and other required work carried out. Up to date, none of the inspections have ever required the turbine runners to be removed.

Initially, the repair took three to four months. Most of this time was in cavitation repair. Now, however, cavitation repair takes as little as two to three weeks and an additional week is allowed for other items.

TURBINE PROBLEMS

There has been remarkably little trouble with the turbines. There has been cavitation damage on the runner and the wicket gates, mainly on the low pressure side near the trailing edges. Also, there has been some cavitation damage just at the top of the draft tube.

The solution has been to repair the cavitation damage on the runner and the gates with stainless steel welding and to run a small band of stainless steel one foot high around the top of the draft tube.

There has been some problem on the equalizing lines. On two units some cavitation damage, close to the head cover within the equalizing lines was noticed. This first showed up as pin holes and the maintenance crew removed and replaced the affected parts. A comment made was that there are probably other units ready to fail, but they haven't done so yet.

Some wicket gate bushings are now showing signs of wear and are losing packing. The plant is now converted to Teflon packing, but the packings are still being lost. Three to four wicket gates need repacking each time the unit is dismantled. There is very little space to do this packing work.

They have had some, but very few, shear pin failures. In most cases a failure of the shear pins, was tracked down to foreign objects jammed in the gate. In one exceptional case 16 pins broke at the same time. Following that incident, the manufacturer put friction devices on the wicket gates.

One serious problem related to the bearings involved the babbit falling out. No explanation for this incident was found as yet.

A wearing ring broke in two on Unit 4 runner. The problem was solved by cutting into the runner, repairing the seal, and then rewelding the runner.

The drain line on one head cover was found to be filled with concrete.

One unusual occurrence in this plant is a very large number of snails in the turbine pit.

GENERATOR PROBLEMS

Generators were manufactured by Westinghouse. Units 1, 2 and 3 had 207 coils on the generator; Units 4, 5 and 6 had 340 coils. Units 1, 2 and 3 have been rewound because of loose wedges, and coil slippage and failure. The coils started to fail after only four years. Operators managed to keep them going and finally rewound them completely with new stator laminations, prior to 1980, with 340 coils to match the other three units.

Some breakage of the flexible connectors between the damper winding end connectors was experienced as well. These were redesigned to solve the problem.

The high pressure oil pump is turned off when the unit reaches 34 rpm (20%) on startup, and restarted at 34 rpm on the unit shutdown. The brakes are applied at 34 rpm on shutdown.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

Replacement parts for the 480 V switchgear are hard, or impossible, to obtain. There have been few failures of circuit breakers. These failures have been

associated with aluminum cable which have become loose over a period of time due to metal flow under the clamp.

There have been four failures of the 13.8 kV switchgear (13.8 kV, 2000 Amp, manufactured by Westinghouse). The failures occurred in the arc chutes and resulted in limited damage. The suspected cause of the failure was moisture absorbed by the arc chutes. There have been no major problems with obtaining the spare parts for the breakers.

There have been no failure in the main transformer since the start of the commercial operation. (One failure occurred during construction.)

One excitation transformer failed during re-energizing following a major unit overhaul. This transformer had been stored outdoors during unit overhaul and may have absorbed moisture. (The transformers are now stored indoors.)

As initially installed, the oil level switches in the turbine guide bearing oil reservoir were grounded on one side thereby putting a ground on the D.C. system. The switches had to be changed to a different type.

The upper reservoir has float-operated level switches to call an alarm at El. 865 and to simultaneously trip all units at El. 866. The pneumatic system sends an analog level signal to the powerhouse. The alarm and trip systems are tested periodically.

CONTINUING CIVIL AND HYDRAULIC PROBLEMS

The main civil problem is leakage in the upper reservoir. Two sources of leakage were identified. First leak was tracked down to the left side of the intake channel which had leaked so badly that in recent months a very long cutoff wall was constructed by excavating to the depth of 55 feet and refilling with a new clay core. The second leak is through the joints between the concrete slabs which line the intake channel. The water leaking through the joints washes out fines from behind the concrete lining. This has caused major cracking of the slabs when the intake channel was refilled following drawdown. Cracking of the lining has been a continuing problem and maintenance has included of refilling the joints and occasionally recasting new slabs.

A major problem has been with the upper intake trashracks. It appears that the trashrack spacing was less than that of the lower intake trashrack and leaves and

debris were pumped up and caught on the inside of the intake trashrack mesh. As a result, an entire trashrack failed. It was at first thought that the trashrack was not strong enough so reinforcement was installed. The trashrack then failed again. The new trashrack was modified with larger spacing between bars.

Some trashrack parts were swept into the spiral case of one unit during the first failure, and had to be cut out.

COMMENTS AND IDEAS

There are a number of items which the plant staff felt were important in consideration of future plants design.

- More room in the turbine pit, to allow easier access to wicket gate stems.
- The definite exclusion of a floating packing box. This has been a real problem for them and they have modified their packing boxes on all the units.
- As much stainless steel as possible on the wicket gates.
- A valve in the oil lines so that the strainer can be changed without pumping all the oil out.
- A larger slip ring compartment, to permit inspection and replacement of brushes.
- An elevator for freight and personnel.
- Venting of the blow down air directly to the outside.

The staff also pointed out a near accident with the lifting beam for the rotor. This is a typical lifting beam with an eye for the crane hook which, together with the beam, had been painted. At one time the operators noticed some slight cracking of the paint on the hook. When the paint was removed, they discovered that the hook had cracked 80% through. The lesson here is that the highly stressed components should not be painted.

ELECTRIC POWER RESEARCH INSTITUTE
HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-19 - SAN LUIS

VISIT DATE - 17 DECEMBER 1985

OWNER: U.S. Bureau of Reclamation

OPERATOR: Department of Water Resources, State of California

OWNER'S REPRESENTATIVES:

Don H. Fleenor	- Chief, Plant Operations Branch
Morris M. Devlin	- Chief, Electrical/Mechanical Maintenance Section
H. Duane Knittel	- Chief, San Luis Field Division
Lonnie D. Long	- Hydroelectric Power Maintenance Supv.
Thomas W. Hammond	- Hydroelectric Power Operations Supt.

EPRI REPRESENTATIVES:

B. E. Sadden	- MKE - Civil Engineer
J. L. Carson	- MKE - Mechanical Engineer
W. R. Moon	- MKE - Electrical Engineer

GENERAL AND PLANT DESCRIPTION

San Luis pumped storage scheme was not operating at the time we visited the plant.

The San Luis plant is an indoor type powerhouse containing eight Francis type pump turbines and synchronous generator/motors with the nameplate rating of each as follows:

	As Turbine	As Pump
Net Head	197 ft	290 ft
Output	54 MW	1375 cfs
Speed	150/120 rpm	150/120 rpm

The units have no wicket gates and therefore both pump and generate at a power determined only by the net head. Six motor/generators have two rotors and stators for speeds of 120 and 150 rpm. Two units operate at 120 rpm for low head operation and 156.5 rpm for pumping at higher heads. A butterfly valve is used for shutoff.

Roller-mounted gates and stoplogs are located at the upper reservoir (San Luis) and stoplogs at the lower reservoir (the forebay), with the trashracks at both. Initial operation was in 1966.

OPERATIONAL ASPECTS

The San Luis plant operates on an annual cycle, pumping in winter and generating in summer. The exact schedule depends on the power market, availability of surplus water, and release requirements.

The plant is available for pumping or generating at any time. In 1983, operations changed when the existing power company contracts ended. Those contracts were made when the project was built. In 1987, operation is as follows: typically in fall and winter the pumping is done as much as possible in off-peak hours from 10:00 p.m. till 8:00 a.m. from September through to April and sometimes all day; about the 1st of June the plant moves into a generating mode so summer usage is generally base load from 7:00 a.m. to 10:00 p.m with no pumping. Generation average is 338 GWh/year. Normally, the water scheduling is done by the Sacramento office. During the generating mode, the water delivery schedule is modified to match the power output. The units run rough when pumping at high head and 150 rpm. The normal head range is 177 to 326 feet, with a minimum of 100 feet. The change between the 120 and 150 rpm generation is at 190-foot head. Starting is across the line. Starting can be either with the unit watered or unwatered, but only watered starts are made because of the tremendous transients during the watering process.

The units are not operated as synchronous condensers.

The time required to bring the unit on line and accelerate to 150 rpm is 50 seconds. On shutdown, valve closing is initiated and the circuit breaker tripped when the valve is 5% open. Brakes are applied at 30 rpm.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

Inspection of the units takes four weeks and is performed every two years. This inspection is carried out for two units at a time but there is little dismantling in that time. There is also a preventive maintenance program which is carried out without taking the units out of service.

There was some cavitation damage below the runner initially, which was repaired and has not recurred.

TURBINE PROBLEMS

Some problems were experienced in the depression systems during the initial operation. The valves to maintain the water level were changed. However, the depression system has not been used since 1967 because of high pressure transients. Starts are now made with the unit watered.

Brakes have experienced seal failures due to corrosion around the seals and have leaked air. The pistons have been chromed to correct this and special circuitry has been installed so that the brake can be tested each day.

There has been major leakage around the headcovers caused by corrosion at the O-ring seal in the headcover.

GENERATOR PROBLEMS

On the generator/motors, the amortisseur winding connecting straps were originally bolted in place. The bolts would work loose and run hot due to the great number of starts. The straps are now silver soldered in place and there have been few problems since.

There has been some corona damage in the stator windings. This is monitored closely.

Some laminations near the top and bottom of the stator have been bending. This problem is monitored closely.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

One of the major problems described was that although the plant is only operated in only a few modes, the wiring in the control panels still exists for more than ten modes of operation. Troubleshooting is therefore more complicated than for other plants on the State Water Project.

There have been some circuit breaker problems associated with the Allis-Chalmers breakers but since changing the operation mode, the breaker has been locked closed. Unit breakers are satisfactory except for the air system which is used for both the operating mechanism and the arc air blast. There have been explosive failures in the unit breakers. Normally, there are two mode changes per day and roughly 600 operations per year. Within the last two or three years, all contacts have had to be replaced. The switchyard circuit breakers are GE Company Type ATB5 and are a high maintenance item. Leakage from the air system is the major problem,

mainly due to temperature variations. Operators believe that delays in delivery of parts is a major problem. For instance, there was a 39-week delivery for a spare part from GE Company. Since the State is required to use the lowest bid for equipment, this often produces an installation of equipment that is already out of date at the time of construction.

CONTINUING CIVIL AND HYDRAULIC PROBLEMS

In 1981, one million cubic yards of material slid down the inside face of the dam. Material was removed, buttressing berms constructed, and the slide repaired.

Failure was caused by batty clays in the foundation which had not been removed during construction, coupled with a rapid drawdown and misplaced riprap.

There has been approximately 18 inches of silt in 19 years of operation but there is, of course, 75 miles of canal to provide for settlement before the water gets to the reservoir. The trashracks have performed excellently; there is no ice and generally there is no trash. Butterfly valves connecting the pump/turbines to the penstocks are opened with each start and are closed with each stop. The butterfly valve seats were originally rubber. These were replaced with brass since the first pump run damaged the seats. However, the brass is non-adjustable.

ELECTRIC POWER RESEARCH INSTITUTE
HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-20 - SENECA (KINZUA)

VISIT DATE - 3 DECEMBER 1985

OWNER: Cleveland Electric Illuminating Company and
Pennsylvania Electric Company

OWNER'S REPRESENTATIVES:

Wes Arford	- Station Superintendent (not at plant during visit)
Gene Conklin	- Supervisor, Safety and Operations
Kevin Long	- Maintenance Superintendent
Joseph Spade	- Operating Superintendent

EPRI REPRESENTATIVES:

A. Ferreira	- EPRI	- Coordinator
B. E. Sadden	- MKE	- Civil Engineer
J. L. Carson	- MKE	- Mechanical Engineer
W. R. Moon	- MKE	- Electrical Engineer
J. Cogan	- MKE	- Geotechnical Engineer

GENERAL AND PLANT DESCRIPTION

The jointly owned Seneca pumped storage plant is located 60 miles southeast of Erie near Warren, Pennsylvania. The upper reservoir is a man-made, circular, asphalt-lined pond nearly one-half mile in diameter and 70 feet deep.

The lower reservoir is formed by an existing dam constructed by the U.S. Army Corps of Engineers.

The water passages consist of a 545-foot vertical, 22-foot inside diameter shaft from the floor of the reservoir connecting to a 2400-foot tunnel of similar diameter. All tunnels are concrete lined and the few hundred feet near the turbine are steel lined.

The powerhouse is an enclosed type and contains three Francis units. Only two units (1 & 2) are reversible and they each have a nameplate rating as follows:

	As Turbine	As Pump
Net Head	646 ft	700 ft
Output	162 MW	3200 cfs
Speed	225 rpm	225 rpm

Of particular interest is the draft tube arrangement. Unit 1 discharges into the lower reservoir, Unit 3 (not reversible) discharges into the river downstream of the plant, but Unit 2 can discharge either way. Discharging into the river downstream enhances the head but is only allowable at certain conditions. Unit 3 is used for synchronous starting and 30 MW of generation discharging only to the downstream of the lower pond.

Construction of the Seneca plant began in spring 1966 and was completed in May 1969.

On the visit day the plant was operating normally with Unit 2 on line, but during the day experienced a forced outage due to switchyard icing described under "Maintenance, Scheduling, Availability and Outages" below.

OPERATIONAL ASPECTS

The station is manned 24 hours a day, seven days a week, and machines are loaded by operators following the instructions from the Cleveland office of the power pool. Usage averages six mode changes per day, but may vary from four to 14, with eight hours of nighttime pumping. Unit 2 output is from 125 to 175 MW when discharging in the reservoir and up to 225 MW when discharging in the river. Unit 1 has a maximum output of 175 MW.

A nuclear plant is soon coming on line in the system so Seneca expects to pump more during the night to take advantage of available power. They will therefore generate more during the day and overall usage will increase.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

Annual maintenance is restricted to two weeks on each large unit and one week on the small unit. The most important work that is regularly carried out at these times is cavitation repair but the quantity of weld metal deposited has not been measured. There has been no major overhaul.

Major recent forced outages (including one on the day of visit) have been because spray from the spillway freezes on the switchyard insulators (the switchyard is

mounted on the roof of the powerhouse). To overcome this, heating lamps are installed in the switchyard directed at the insulators. On the day of our visit, one of the lamps had become loose and was not directed at an insulator, which froze and then shorted, causing a trip.

Availability is estimated to be 97 to 98%, not including scheduled outages. If the scheduled outages are included, plant availability is estimated at 94%.

Pumping/generating ratio is about 1.38.

Brakes are applied at 25 rpm on Units 1 and 2.

TURBINE PROBLEMS

The pump turbines must run at minimum of 125 MW. Vibration noise occurs below this load, accompanied by high loads on the thrust bearing. For instance, if the units run at speed no-load, the thrust bearing temperature increased dramatically.

Shear pins were broken on Unit 1 during pumping four years ago. The probable cause of failure was loose keys, together with a possible governor problem.

Unit 1 runs smoothly; Unit 2 needs smoothing air in the pumping and generating modes. It is likely that the rough operation is caused by the bifurcation and valve in the draft tube.

Cavitation repair is performed using templates to keep the contour of the blades unchanged. However, after the nose cone fell off of Unit 1, damaging the blades, some reworking was required; six inches was cut off the tip of each blade. The basic contour of the blades was maintained and no efficiency change was evident.

The runner coupling bolts broke, allowing the wearing rings to rub. The subsequent wearing ring damage resulted in an increase in design clearances. The wear rings are anticipated to be replaced in the early 1990s.

The cover plate on the runner crown came loose and laid on the runner, which caused unbalance vibration. This probably contributed to runner bolts breaking.

GENERATOR PROBLEMS

Thrust bearings are of marginal capacity. Normally, one of two high pressure oil pumps is run continuously to help hold the temperature down.

Generator stators of both large units have been rewound, Unit 2 in 1982 and Unit 1 in 1985. On Unit 1, all iron laminations were replaced due to corrosion and shorting between laminations, resulting in local overheating.

Corona damage to the stator windings has been severe; insulation completely disintegrated, thus causing both units to be rewound.

While one stator was being rewound, an excess of oil film was found and fans and monitors were installed to prevent future vapor buildup.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

Brakes are now applied at 25 rpm, as against the original 125 rpm. Both brake rings have been replaced due to overheating resulting from braking at the high speed. An excessive wear was noted.

CONTINUING CIVIL AND HYDRAULIC PROBLEMS

The most important problem at Seneca has been the leakage in the upper reservoir, which has an operating range of 70 feet.

Leakage in the upper reservoir occurred in naturally-occurring depressions, which formed the reservoir floor. Initially, remedial action consisted of pouring a concrete wall along the leakage zone. This did not work, as the leakage continued. Next, the depression was filled with 350,000 yd^3 of overburden, a clay bed laid on top, and a PVC liner added. This represented an area of about ten acres which is not lined with asphalt. It was intended that at some time the whole floor be lined with asphalt and this was performed in 1984, 1985 and 1986.

The leakage is presently monitored from measuring weirs connected to toe drains in the structure.

The upper reservoir does not exhibit significant silting. There also are no icing problems. Ice breaks up around the fringes of the reservoir. Ice has never damaged the upper reservoir lining, at least as far as can be determined.

Occasional cracks in the asphalt tended to be large during the first few years of operation. Cracks now occurring are only 1 or 2 inches in diameter and they can be seen by a depressed area around the crack. The last hole was spotted in 1982.

Every few years liner cracks are sealed and a seal coating sprayed on. For packing, a rubber/plastic compound is heated up and poured in. When a large leak is suspected, as indicated by the toe drain weir monitors, the reservoir is drained.

The internal ramp, or the edges of the ramp, have never caused or accentuated any problems.

The spillway was designed to pass pumping capacity of all pumping units. It consists of a broad-crested weir 100 feet wide connected to a chute that extends down the outer slope of the dike. It consists of pea gravel, an easily eroded and free-draining material, and is provided on the reservoir side with the same asphaltic concrete as the rest of the dike. The fuse plug was designed to begin washing out when freeboard on the dike is reduced to three feet.

The rock is sandstone and shale. A thick shale bed underlies the upper reservoir. The shaft and tunnels are concrete lined. Steel penstocks project into the tunnels adjacent to the powerhouse.

Some cracking in the high head shaft concrete near the top has occurred. These cracks were closed by grouting.

ELECTRIC POWER RESEARCH INSTITUTE
HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-21 - SMITH MOUNTAIN

VISIT DATE - 7 JANUARY 1986

OWNER: Appalachian Power Company

OWNER'S REPRESENTATIVES:

Dale Fisher - Superintendent

EPRI REPRESENTATIVES:

A. Ferreira - EPRI - Coordinator
B. E. Sadden - MKE - Civil Engineer
J. L. Carson - MKE - Mechanical Engineer
W. R. Moon - MKE - Electrical Engineer

GENERAL AND PLANT DESCRIPTION

Smith Mountain Pumped Storage Plant is located at Smith Mountain Gap on the Roanoke River 40 miles southeast of Roanoke, Virginia. Smith Mountain Dam, which forms the upper reservoir, is a 227-foot high, 816-foot long, double curvature arch dam. The upper reservoir is approximately 40 miles long. The lower reservoir is formed by the Leesville Dam some 17 miles downstream, which is a 90-foot high, 920-foot long concrete gravity dam. The semi-outdoor powerhouse, located at the base of the dam, houses five units. Each unit has a separate steel penstock that penetrates the dam at a different level. The penstocks for Units 2, 3 and 4 are 26 feet in diameter, while those for Units 1 and 5 are 20 feet in diameter.

Three of the five units are reversible pump-turbines: two are rated at 65 MW, while the third is rated at 105 MW. The nameplate ratings are as follows:

	Units 1 and 5		Unit 3	
	As Turbine	As Pump	As Turbine	As Pump
Net Head	180 ft	205 ft	170 ft	188 ft
Output	65 MW	3,900 cfs	105 MW	7,080 cfs
Speed	105.9 rpm	105.9 rpm	90 rpm	90 rpm

In the powerhouse, located at the base of the arch dam, space is at a premium. In order to dismantle machines, concrete deck segments can be placed over the two small units (at the ends of the powerhouse) on which equipment can be stored. There are no turbine shutoff valves. There are wheeled gates and trashracks at both the upper and lower reservoirs. Initial operation was in 1965. Unit 3 was installed later and first operated in 1980. On the day of our visit no major maintenance was in progress.

OPERATIONAL ASPECTS

The plant is operated as a peaking plant and for system frequency control. Operation is remote, with only maintenance personnel stationed at the plant.

The two conventional units operate continuously, either generating or as synchronous condensers. Much of the time, the three pump units also operate as synchronous condensers. All units are loaded on an economic dispatch basis, i.e., when the energy is the most economical to meet the load. The units are operated so as to equalize the operating hours on each.

Units 2 and 4 generate at between 40% and 90% gate. Units 1, 3 and 5 generate generally at 80% gate. Unit 3 pumps at 40% gate, while Units 1 and 5 pump at 65% gate. Air is admitted at all times during pumping and between 40% and 55% gate on Units 2 and 4 when generating to smooth out vibrations and noise. Trashracks at the upper reservoir are raised when pumping. Draft tube trashracks on the pump units are in place at all times.

The pump units utilize reduced voltage starting. On shutdown, brakes are applied at 30% speed and released six minutes after the unit has stopped. The high pressure bearing oil pump runs at unit speeds below 90%.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

The normal complement of men is a crew of 12 for maintenance work for Smith Mountain and Leesville plants. All the maintenance men can operate if necessary. There is one man on duty at all times.

There is an annual maintenance period of two weeks for each unit. During this time, ten additional maintenance personnel are employed to inspect all aspects of the machine. Cavitation repair needs are assessed and scheduled. Cavitation repair is generally required at about a seven-year interval. Major overhaul has been limited to pulling the rotor every five years for checking. None of the pump

turbines have been taken apart since 1969. There is no major overhaul of the pump turbines planned at present.

TURBINE PROBLEMS

The wicket gates on Unit 1 were damaged in 1969. They were of cast steel and three were lost in a cascade failure. The entire set of gates was replaced with a set of fabricated steel gates. Damage to the runner was repaired in place. All new gates for Units 1 and 5 have been made by Allis-Chalmers to exactly the same shape as the original ones and friction devices have been added to the operating mechanism.

GENERATOR PROBLEMS

Units 1, 2, 4 and 5 have all been rewound due to stator coil failures. Individual stator coils were cut out and the units were kept running following an individual failure, but eventually the generators were rewound using epoxy-insulated windings.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

The original air-blast 13.8 kV circuit breakers for Units 1 and 5 have been replaced with vacuum circuit breakers due to failure of the original Unit 5 equipment.

CIVIL AND HYDRAULIC FEATURES

The units can be unwatered only by lowering the head gates, which can be remotely operated by the control center at Roanoke.

There are log booms in the forebays at both Smith Mountain and Leesville and in the tailrace at Smith Mountain. The latter one is mechanical and is lowered only during pumping. Units 1, 3 and 5 have movable trashracks in the upper intake that are lowered for generation and raised for pumping. The trashracks in the lower intake are always in place. One of the original upper racks was destroyed during initial pump startup.

ELECTRIC POWER RESEARCH INSTITUTE
HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-22 - TAUM SAUK

VISIT DATE - 7 MAY 1986

OWNER: Union Electric Company

OWNER'S REPRESENTATIVES:

Dan Jarvis - Plant Superintendent

EPRI REPRESENTATIVES:

B. E. Sadden - MKE - Civil Engineer
J. L. Carson - MKE - Mechanical Engineer
W. R. Moon - MKE - Electrical Engineer

GENERAL AND PLANT DESCRIPTION

Taum Sauk is located 90 miles southwest of St. Louis in Reynolds County, Missouri. It was the first pumped storage scheme in the world with a completely isolated upper reservoir. The plant is a conventional pumped storage installation with an upper reservoir artificially formed by a rockfill dike about 6000 feet in circumference and with a maximum height of about 105 feet. The rockfill was not compacted and a concrete facing was placed on the inside slope with an 8-foot high vertical parapet wall. The floor of the reservoir was sealed with asphalt. The crest of the parapet wall is at El. 1599. An interesting feature of the reservoir is the access tunnel through the embankment and into the reservoir, using a hinged bulkhead gate.

The water conduit includes a 431-foot vertical shaft and a 4764-foot long tunnel, both lined with concrete, and a horizontal steel lined tunnel 1807 feet long, bifurcating into two penstocks for the two reversible pump turbines. The powerhouse is a semi-outdoor arrangement, serviced by a gantry crane. The nameplate rating of each unit is:

	As Turbine	As Pump
Net Head	790 ft	764 ft
Output	220 MW	2650 cfs
Speed	200 rpm	200 rpm

The lower reservoir is formed by a dam approximately 360 feet long and 60 feet high across the East fork of the Black River. A major rock cut forms the tailrace channel protected by a dike.

The machines were first placed in service in 1963. Starting of the units is by a pony motor. On the day of our visit, no maintenance work was being performed.

OPERATIONAL ASPECTS

Taum Sauk is no longer used much. During the first 15 years, it was used on a daily basis, pumping from midnight to 7:00 a.m., and then generating at the normal peak periods. However, since the modern steam plants are now able to generate over a wider load range, generation at Taum Sauk is random. The plant is used for an emergencies on the system. It may not generate all week and operate for only two to three hours when needed. Previously the plant was idle for periods of two to three weeks, but starting was unreliable because of sticking pressure and limit switches. Now each unit is operated once a week to make sure that the plant will start when necessary.

The plant is remotely operated. Generators are block loaded.

The units operate at a minimum loading of 150 MW. There is considerable unit vibration below 100 MW. The units are rated at 175 MW, but they have been operated at 220 MW for extended periods. Air is admitted below 30% gate opening but 150 MW is 50% gate opening, so the air is only admitted briefly. Wicket gate openings for pumping are set manually between 42% and 47%, depending on the head.

On shutdown, brakes are applied at 30 rpm (15% of rated speed). High pressure oil is supplied to the thrust bearing below 150 rpm. Starting for generation takes five minutes, and about fourteen for pumping.

The best pumping-generating ratio that the plant could achieve is probably around 0.60. Unfortunately, leakage from the upper reservoir pushes this figure down a bit since the average leakage is probably around 15 cfs from this 55-acre reservoir.

The units can run as synchronous condensers but this practice has been abandoned because operation takes more power than at first anticipated.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

The units are down for five weeks every other year for maintenance. In 1986, they were out for one week each, resulting in an availability of about 95%.

The schedule outage is used to repair the joints in the upper reservoir. In 1985, the opportunity was taken to repair a seal in the spherical valve at the same time. The units are inspected once a year. The major overhaul of Unit 1 took place in 1973 and for Unit 2 in 1974.

Union Electric has contracted the work for the major overhauls. Unit 1 was overhauled in 1973 and Unit 2 in 1974. There has been no disassembly of the generator during the turbine overhaul and all work has been completed from below. The time for each overhaul was approximately 3-1/2 months using two 10-hour shifts for the disassembly of the turbines.

The plant is maintained by a crew of three mechanics, three electricians, two utility men and the manager, who work eight hours per day, five days a week.

TURBINE PROBLEMS

During the plant startup an excessive vibration, independent of speed, was noticed at various locations. This was corrected by injection of air, and the only in-service problem which remained was a variation in downthrust. It was found that blanking off the pressure equalizing lines (and introducing high pressure water above the runner) while generating, and opening the pressure equalizing lines during pumping stabilized the downthrust. This was achieved within a short time of commercial operation.

Turbine problems have been limited to the cover plates on the split runner and the upthrust problem. These two problems are connected.

The cover plate over the top of the split in the runner came off in 1975. In an attempt to avoid any recurrence of this, the staff removed the cover plates and filled the top of the runner crown of Unit 1 with epoxy. Upon starting, they noted an increase in deflection of the thrust bearing bracket due to excessive downthrust. Balance lines from the top of the runner to the draft tube were again installed. However, this measure resulted in excessive runner runout. To overcome

this, they installed a valve in the balance line and adjusted the thrust to balance temperatures in thrust and guide bearings. Although the epoxy had been put in very carefully, part of it came out and prompted the removal of the whole epoxy fill and installation of another welded steel plate.

There have been two near-floodings of the powerhouse associated with the balancing lines. Vibration caused a weld in the balancing line to crack and the powerhouse was partly flooded as a result. The staff installed flexible pipe connection which also failed and again partly flooded the plant. No cavitation damage has ever been observed in the equalizing lines.

During the major overhaul, there was a significant amount of cavitation repair performed, with 200 square feet of stainless steel overlay placed on each wheel, totaling approximately 2,000 pounds of weld material. The original overlay was approximately six square feet per blade. At the same time, the blades of the wicket were overlaid with stainless steel type 309, with approximately two square feet per gate. Epoxy was tried for cavitation repair on the wicket gates, but it didn't hold.

Other turbine problems have included the dislodging of the No. 1 runner nose cone and subsequent damage to the runner, and a problem with turbine bearings running hot. The bearing oil system was modified from a gravity to pressure supply.

Lower stationary runner seals were lost from both machines. For some time, makeshift seals were used.

The draft tube lining was repaired with fiberglass in an attempt to overcome the effects of cavitation.

GENERATOR PROBLEMS

The generators have had very few problems. Coil wedges routinely creep out and must be driven back into the slots. Some of the stator RTD's have failed open, thus there is no temperature indication of those points. The lower air deflector plates had inductive heating problems; they were replaced with fiberglass plates. Brake plates warped when the brakes were applied at too high a speed by the centrifugal speed switch. The gear ratio for the speed switch was changed to give a more positive response.

The upper and lower guide bearings and the thrust bearings have had no problems as long as they are operating within their design ranges, i.e., with the down thrust from the turbine at its design value (see Turbine Problems above).

There have been no problems with the 12,000 horsepower starting motor, liquid rheostat system, or excitation system.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

The automatic control system has worked with no major problems. The original Data Logger/Volume Totalizer needed regular checks and adjustments and many of its features never functioned. It was replaced in 1985 with a new computer system and, to date, it has worked properly with very little problem.

The auxiliary electrical equipment has worked very well over the life of the plant, with very few problems. There have been no problems with the main power transformer, station service transformer or station service equipment.

The switches on the blow-down level control were mercury tilt type, which didn't operate well. These were changed to probe type.

There have been occassional problems with the main inlet valves. Oil operated seal piston O-rings leaked oil into the lake. The system was changed to water operated. There has also been leakage under the stainless steel sleeve on the trunnion packing gland which has been welded. Finally scoring on the rotor and piston seals has to be occassionally machined.

A 10-year inspection revealed several bars missing from the tailrace trashrack, probably due to vibration.

CONTINUING CIVIL AND HYDRAULIC PROBLEMS

The main civil problems on this plant are associated with leakage from the upper reservoir and water conduit lining.

Out of 6000 feet of conduits, 1800 feet is steel lined. Near the upper end of the steel lining, a spring was flowing into the tunnel, therefore the designers included a drain for the full 1800-foot length of the steel lining. The spring has a high calcium content which finally resulted in plugging the drain line and in 1967, the lining buckled during the penstock draining. The bulge was left unattended and in 1969 when the penstock was inspected again, there was a much bigger bulge, 100

feet long. The drains were then cleaned out by a roto-rooting device and the bulge collapsed upon the penstock refilling. The last time the penstock was inspected (in 1985), the bulge was even bigger. More drain cleaning was performed and the penstock bulge collapsed again on refilling. This fact was checked by inserting dye bags underneath the penstocks so that when the penstock was refilled, it broke the dye bags releasing the dye into the drain lines.

The upper reservoir is formed by a sluiced, dumped rockfill dike with approximately one foot of gunite on it and copper and rubber joints. The sluiced dump rockfill has consolidated shaping the upper reservoir panels strangely. The major leakage is from the joints. The joints have to be raked out and refilled with a new sealing compound every few years. This is a constant source of maintenance for the staff. They have attempted to mark the joints that have been repaired by using various colors of calking but essentially all joints have to be attended to every few years.

Over-pumping is dealt with by two level monitoring systems directly wired to the powerhouse. There are two sequential alarm signals and one emergency trip signal on each system. Battery back-up power is provided at the upper reservoir.

There is a penstock filling pump in the plant but usually by the end of the maintenance outage little time is left to restart the unit. The penstock is then refilled operating the unit in the pumping mode against a very low gate opening, say two or three percent. This allows the penstock to be filled slowly at first and then as the head builds up against the pump, the gates are opened completely, and the reservoir is filled in 7-1/2 hours with two machines. Using the fill pump, it takes three days.

There has been a minor problem at the end of the tailrace channel where some large rocks were placed, in the lower reservoir, to prevent the river gravel from entering the tailrace. However, the rock was dislodged and entered the discharge channel. The rock was replaced by a new dike.

COMMENTS AND IDEAS

Were the plant to be built again, the staff suggest the following list of items:

- Stainless steel runners and wicket gates and non split runners.
- An improved drainage system for the penstock.
- A compacted upper reservoir embankment.

- The inlet valve seal operated by water rather than oil.
- An upstream seal on the inlet valve.
- Gates on the upper reservoir.
- A bigger freight elevator.
- A crane that can pull a rotor without disassembly.
- Full set of templates of the runner available to maintenance personnel.

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HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-23 - WALLACE DAM

VISIT DATE - 13 MARCH 1986

OWNER: Georgia Power Company

OWNER'S REPRESENTATIVES:

J. A. Nutt	- Plant Manager
J. R. Pope	- Asst. Plant Manager
Ed Davis	- Senior Instrument Technician
T. W. Wright	- Foreman
C. E. Harrison	- Foreman

EPRI REPRESENTATIVES:

B. E. Sadden	- MKE - Civil Engineer
J. L. Carson	- MKE - Mechanical Engineer
W. R. Moon	- MKE - Electrical Engineer

GENERAL AND PLANT DESCRIPTION

Wallace Dam and power plant are located on the Oconee River in the Altamaha Drainage Basin at the headwater of Lake Sinclair. Wallace Dam, which forms the upper reservoir is a concrete gravity/earthfill dam, the powerhouse being an integral part of the structure. The total length of the dam is approximately 2395 feet and the height 117 feet.

The powerhouse section of the dam, semi-outdoor, approximately 530 feet long and contains four Francis reversible units and two conventional propeller type turbines serviced by a gantry crane. Maintenance sheds and facilities are remote from the dam. The lower reservoir is formed by Sinclair Dam approximately 20 miles downstream.

The reversible units are each rated as follows:

	As Turbine	As Pump
Net Head	89 ft	98 ft
Output	54 MW	6500 cfs
Speed	85.7 rpm	85.7 rpm

During normal operation of the plant Units 3 and 4, the conventional units, are favored.

Unit 6 was commissioned in November 1979; all other units were commissioned in 1980.

At the time of our visit, all units were operational but some control wiring was being repaired.

OPERATIONAL ASPECTS

Wallace Dam units are controlled at the site but are dispatched by telephone from Atlanta. Generally, the units are block loaded. They are able to operate the units as synchronous condensers but do not do so because the operators are concerned about losing runner seal cooling water. Synchronous condensing is done on the conventional units.

Starting is direct across the line. The sequence is to start all the pumping units that are scheduled to be used and then load them all in order.

In 28 days they have had 60 starts in generator made. The staff indicated that pumping would usually commences every night around midnight. Starting time for pumping is three minutes, of which 30 seconds is required to get up to speed, two minutes to prime and 30 seconds to load. When generating, the units can generally get up to speed in between 25 and 30 seconds and can therefore bring on the full plant output of 321 MW in approximately eight minutes. The minimum limit on generation is 40 MW per unit because of cavitation, which corresponds to a 60% gate opening. An 80% gate opening is most efficient, which represents 57 MW in generating mode. At 100% gate opening, units can attain generation of 59 MW. Pumping is performed at approximately at 63 MW, which is 65% gate opening. Other gate openings have been tried, but 65% is the most efficient. No air is admitted during pumping or generating.

Records of availability for 1985 showed an average of 92.7% for the four reversible units.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

At present, each unit is inspected semiannually. Two weeks are scheduled per inspection totaling four weeks per year, but at present only one week is used for each inspection. During this time, clearances are checked and most items of equipment are inspected, including bearings and other items. Contract labor does the dismantling. If necessary, cavitation repair is done at the same time. There is also an annual inspection of the top and bottom trashracks by divers.

Overhauling of one unit by a contractor took 18 weeks. At that time, 2-1/2 to 3 years of cavitation damage, totally 3000 lbs. of weld material, was repaired. Bearings will be overhauled every five years.

For the maintenance of Wallace plus three other plants, there are 54 people; usually there are two operators per shift.

TURBINE PROBLEMS

The turbine runners are split. The cover plates over the bolts are welded on and have given no problems. The pump-turbines have individual servomotors for the wicket gates which have operated satisfactorily except for an occasional seal ring failure.

The principal problem have been the runner wearing rings. In 1980, the lower early rings of sized on Unit 1 and locked the unit. This resulted in 16 months outage. The plant owners possess only one set of stoplogs, so this restricted the scheduling of the work on other units. The are giving ring was bolted on originally and larger bolts were installed on Unit 1. When the unit was inspected again in 1983, the bolts had again burden, so units were modified to include a shrunk on rotating ring. This proved satisfactory. In each case, the runner had to be remachined.

Because of the delay caused by the failure on Unit 1, cavitation repair could not be scheduled. By the time the plant maintenance personnel were able to commence cavitation repair on other units, the cavitation damage was so bad, particularly on the lower band, that each runner had to be removed to avoid distortion due to the repair welding. Cavitation damage was generally inside the lower band and the low pressure side of the blade. A template was made of the bucket with the least cavitation damage for use when repairing other buckets but no improvement was discernible.

Bearings were originally sprayed-on babbit. Two of the bearings have failed and been replaced by poured babbit.

All bushings on the wicket gate stems were worn because of abrasive silt in the water. The bushings have been replaced and chevron type seals have been installed. On the other hand, the wicket gate end seals have had nothing more than normal maintenance.

There is no vibration monitoring systems on the units. The manufacturer wanted to one, but Georgia Power declined. Now the manufacturer wants to put one on Unit 1 at no charge. The manufacturer maintains that the vibration is the cause of turbine wear and problems but Georgia Power disagrees.

The drains on the headcover are not adequate and it was necessary to install air driven pumps to handle leakage. In addition, there are no holes in the webs of the headcover, which retains a large amount of water.

There has been some cavitation on the equalizing lines. As yet, these have not failed but are being watched.

Priming of the units has presented some problems. Sometimes the units will prime and sometimes not. Sometimes it takes three minutes to prime the unit and occasionally it has taken as long as ten minutes. This has happened with no regard to any particular unit. Staff have decided that a plug of air was getting caught in the turbine and they have had to break this by opening the gate slightly. The problem has been overcome by connecting additional air evacaution lines to the inspection holes in the headcover.

GENERATOR PROBLEMS

The units have never been rewedged, although some individual wedges have been tightened. The units are high potted every five years.

On the rotors of all pump units, the flexible connection between the amortisseur (damping) bars have broken loose at the silver soldered joint.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

A major problem has been the field circuit breakers. Contacts have been repeatedly burned and arc chutes damaged. It cost of $3,000 to rebuild the contacts and the arc chutes. The problem was that the field contacts and the discharge resistor

contacts were overlapping (both closed) for about one cycle when the field breaker is opened, and the high DC currents were causing the contacts and arc chutes to fail. Changing the relaying to open the field breaker at the best time has cured the problem.

Sump level switches were Magnatrol, which failed, resulting in a couple of floods in the sumps. The switcher have been replaced with simple float switches. The pumps originally required frequent maintenance and have been replaced.

The unit circuit breakers are the oil filled type. The circuit breakers are now inspected on a 6-month schedule.

Bulb type temperature switches, which are mounted on the stator frame, have caused a few trips due to vibration during startup of the units.

CONTINUING CIVIL AND HYDRAULIC PROBLEMS

There are leaks in the dam and in the powerhouse. Generally they are seasonal and many have been grouted.

The water is dirty but there is no silt problem in the reservoir. Silt is clearly circulating in the system but does not settle anywhere, in significant quantities.

There are dam movement gauges read biannually. One or two dam monoliths have moved up to 3/8 inch.

COMMENTS AND IDEAS

If the plant were built again, the staff would have head gates in each unit; they would not have individual servomotors; and they would ensure that chevron packing was used for the wicket gates.

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CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-24 - YARDS CREEK

VISIT DATE - 4 DECEMBER 1985

OWNER: Jersey Central Power & Light Company and
Public Service Electric & Gas Company

OWNER'S REPRESENTATIVES:

Fred Kunich	- Station Manager
Jeff Geuther	- Station Engineer

EPRI REPRESENTATIVES:

A. Ferreira	- EPRI	- Coordinator
B. E. Sadden	- MKE	- Civil Engineer
J. L. Carson	- MKE	- Mechanical Engineer
W. R. Moon	- MKE	- Electrical Engineer
J. Cogan	- MKE	- Geotechnical Engineer

GENERAL AND PLANT DESCRIPTION

Yards Creek station is a jointly owned pumped storage scheme located near Blairstown in Warren County, New Jersey, placed in service in 1965. The upper reservoir is formed by a number of earth and rockfill dikes totaling approximately 9000 feet in length. The main dike is 70 feet high.

The lower reservoir is formed by an earthfill dam across Yards Creek approximately 1400 feet long and a maximum of 55 feet high. There is a 100-foot wide concrete spillway at the right abutment of this dam. An auxiliary dam 2200 feet long completes impoundment of the lower reservoir. An auxiliary reservoir located near the lower reservoir provides supplemental storage to compensate for evaporation and releases.

The waterways connecting the upper and lower units include a substantial intake channel 35 feet wide and 1500 feet long with a bell-mouth intake to the 20-foot diameter concrete lined tunnel which is approximately 1500 feet long. The lower 218 feet of tunnel is 19-foot diameter and steel lined and connects to an exposed

penstock. The exposed penstock is 1860 feet long and trifurcates into three 10-foot diameter conduits leading to the units.

The station is a semi-outdoor type with an overhead gantry crane. The main structure is 140 feet long and 63.5 feet wide. The nameplate rating of each of the three units is:

	As Turbine	As Pump
Net Head	656 ft	700 ft
Output	113 MW	2145 cfs
Speed	240 rpm	240 rpm

Construction of the plant began in October 1962 and ended in November 1965.

On the day of our visit the plant was operating normally.

OPERATIONAL ASPECTS

Yards Creek is well used and typically generates six to eight hours per day with all three units. There are at least two peaks - morning and afternoon, with an occasional third peak in the evening. There is an average of six mode changes per day per unit. The staff estimates that machines are in operation 70% of a 24-hour period and typically all three units commence pumping between 10:00 p.m. and 12:00 p.m. Low points of operational use are spring and fall. High plant usage occurs in summer and winter.

The plant is operated remotely from Morristown as a satellite of PJM Valley Forge dispatch power pool center. It is attended only during weekdays with one shift for maintenance purposes.

Synchronous condensor operation is possible, but the operating staff have found that the 100 psi depressing air system is unable to allow changing from generating to spinning in air. Operation as synchronous condensors is limited to the pumping direction. However, this operation has never been required. They have also never been able to synchronize on governor control so have decided to operate on gate limit control.

Pumping to generating ratio is from 1.47 to 1.52 - an improvement can be seen throughout the operating life of the plant and also immediately after major maintenance.

Units are operated at loads from 90 MW to 130 MW under block loading. Smoothing air is injected during both pumping and generating.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

The machines are carefully inspected annually without major dismantling. Two weeks is always scheduled for this work, but it sometimes takes only one week. This inspection usually includes such work as general cleaning, cleaning of carbon from brushes, oil checks, replacement of shaft packing, inspection for leaks, rebuild of valves, etc. It does not include opening bearings or cleaning oil coolers (with the exception of the turbine guide bearing cooler and generator air coolers). A pole voltage drop test is carried out and main parallel disconnects are inspected and rebuilt as required. Main circuit breakers and phase reversal switches are checked, serviced as required and tested.

Dye checks are carried out at the annual inspection at suspect areas of the stay ring for cracks. All valves are checked and O-rings changed if necessary. The runner band valve is inspected as are the depression air system valves. At the annual inspection, cavitation repair is performed as necessary.

Plant maintenance staff is three mechanics, three electricians and one laborer permanently attached to Yards Creek.

For major maintenance, there is a dedicated mobile maintenance group that numbers about 40 men. It is drawn from the staff at each plant, for instance, one of the electricians at Yards Creek is also designated in the mobile maintenance group.

Since 1972 the staff have maintained a graph of the pumping to generating ratio in order to try to discover problems and trends in the turbine before breakdown.

TURBINE PROBLEMS

A copy of the excellent paper "Experiences on Startup and Trial Operation at Yards Creek Pumped Storage Project" was given to the team, which paper gives a frank and detailed discussion of early vibration and other problems.

The original mild steel runners with stainless overlay were replaced with all stainless steel runners in 1970-71. These have not needed annual cavitation repair.

There is some cavitation damage occurring on the stay ring inside of the wicket gates.

A major problem has been cracking of the head cover bolting flange, which was felt by the consultants to be linked to fatigue. When first discovered in 1970, the cracks were repaired by stainless steel welding (stay ring is A148 90/60 casting), but later in 1977 similar cracks were discovered in the short ribs below the bolting flange. The problem was persistent and by 1981-82, the consultants derived a repair procedure. Extra vertical 1-1/2" thick reinforcing plates were welded in place with considerable preheating and stress relieved at a temperature of 1260°F. Holes distorted during this procedure and had to be redrilled. Five months after the unit was back in service, a stay vane crack six feet long and three-and-one-half inches deep was discovered in the #2 stay vane. Seven days after completion of repairs and return to service, a crack three feet into the #1 stay vane and another 30-inch long radial crack through the bolting flange were found. During the drafting of the repair procedure for the original cracking, the finite element analysis had shown minor increase in stay vane stress but not enough to cause such cracks. It is felt that the cracks are probably due to incomplete stress relieving and casting defects, but the problem is still under review.

Problems associated with the new head cover include the failure of the welding of the Nelson studs holding the packing glands for the wicket gates. Also, there was a movement and a slight leakage through the head cover parting joint. Washers were added and the preload increased, which reduced leakage to an acceptable level.

There has been cavitation damage in the equalizer lines, particularly at the 90° and 45° elbows. In addition, fracturing has occurred due to original head cover deflection. Flexible connections (now a Dresser coupling) have been inserted to reduce bending and all lines have been replaced except those embedded in concrete. At present, there is leakage from an elbow in the concrete and the crew are removing concrete to repair it.

On each unit, now only one line is in use as limited equalization is required to minimize thrusts.

Wicket gates have been something of a problem. New wicket gates were ordered in accordance with the original manufacturer's drawings. A manufacturing (or

drafting) error resulted in gates being supplied that were too thick and initially would not open. Eventually, the gates did open and worked for five months, at which time the error was discovered and the gates trimmed to the correct shape.

Cavitation repairs have been carried out in the normal way, except that the maintenance staff have filled cavitated areas with epoxy on occasions to "buy time" before repairing with weld material.

In 1984, the gate linkage was rebuilt because shear pins were failing, apparently due to vibration. Three hundred pins sheared in nine months before the rebuilding was completed.

GENERATOR PROBLEMS

On commissioning, the generators ran with hot windings and insulation deteriorated quickly. The first breakdowns occurred after four years. After seven years, two units were redesigned with modified slot cross-section, new core, and new armature winding insulation (epoxy-mica hard coils). The third unit was rewound using the original core. Subsequently, the redesigned units developed corona problems and failed again. They were rewound a second time with Necobond B "hard coils" in 1977-78.

One guide bearing failed during startup because the bearing cage had not been dowelled. The clearance at the bearing was reduced by the maintenance staff and the bearing failed. Thrust bearings have been outstanding.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

The air blast main circuit breakers were replaced by SF_6 ones during 1985 and 1986 since the originals were out of date, parts were expensive, difficult to obtain, and on extremely long delivery.

Initial problems occurred in air blast circuit breakers, among them air leakage in the operating mechanism. The staff consider that maintenance required on 14.4-kV starting and running circuit breaker is high.

Unit 1 transformer exploded and a second one failed shortly thereafter. Both had to be shipped to the manufacturer for complete rebuilding and were under repair for six to nine months. Two transformers allocated to Longwood Valley Project (which was cancelled) were used while Yards Creek ones were being repaired. The causes of

failure, according to the manufacturers, were the formation of large volumes of nitrogen bubbles and pumped storage operation.

Spherical valve seals have been replaced (this repair will probably have to be repeated every ten years). The penstock was not drained for this operation.

The valve is operated by the penstock water pressure. When the hydraulic cylinders were dismantled, all piston rods were pitted and damaged. All hydraulic cylinders have been rebuilt.

The station was partially flooded twice. First flooding was due to an equalizer line break when no one was present. The second flooding was a result of operator error.

Yards Creek now has its third design of starting reactors. The first design had current limiting reactors which were underdesigned and overheated. Two in parallel worked for a time. Then the reactors were improved but still had deleterious thermal effects on the concrete conductor supports. After an additional two years, the reactors were changed to "laminated" type and there have been no problems.

CONTINUING CIVIL AND HYDRAULIC PROBLEMS

Station personnel are investigating the need for regrouting the junction between the concrete and steel lining in the tunnel subsequent to a report by Chicago Bridge and Iron, to ensure continued effectiveness of the waterstop and minimize external corrosion.

Some leakage through the dam was noted early on during operation, probably due to intrusion of filter material into core. This was probably because of lack of care during construction. A lawsuit was settled in favor of the Owner. The original leakage of 600 gpm has now dropped to 400 gpm and is monitored. Corrosion has affected all of the trashracks. Stainless steel trashracks were placed in the upper reservoir in 1985.

COMMENTS

Recommendations included:

- All critical embedded piping should be corrosion resistant.
- Pump turbine runners should be fabricated of stainless steel.
- Pump turbine wicket gates should be fabricated of stainless steel.

- Spiral case inlet extension joint should include corrosion resistant overlay where in contact with the O-ring seal.
- Weatherproofing of the crane, or a covered area, is very important so that each unit can be dismantled under cover.
- Cleaning and painting of the aboveground penstock is a major task. A penstock underground for 100% of its length would have solved the problem.
- Piston rods for valve operators should be all fabricated of stainless steel.
- An events recorder should be installed.

PAPERS

"Experience on Startup and Trial Operation at Yards Creek Pumped Storage Project," R. J. Swed and K. H. Yang, Journal of Basic Engineering, September 1969.

ELECTRIC POWER RESEARCH INSTITUTE
HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-25 - DINORWIG

VISIT DATE - 1 APRIL 1986

OWNER: Central Electricity Generating Board (CEGB)

OWNER'S REPRESENTATIVES:

Mike Hancock	- Station Manager (not at plant on day of visit)
Ken Newis	- Head of Production
Elwyn Price	- Head of Engineering

EPRI REPRESENTATIVES:

A. Ferreira	- EPRI	- Coordinator
B. E. Sadden	- MKE	- Civil Engineer
J. L. Carson	- MKE	- Mechanical Engineer
W. R. Moon	- MKE	- Electrical Engineer

GENERAL AND PLANT DESCRIPTION

Dinorwig is the larger of the two pumped storage schemes in the United Kingdom, and is presently the largest in Europe. It is located in mountainous North Wales, close to the coast and 11 miles south of Bangor in the county of Gwynedd. In this area there are two nuclear power plants, another pumped storage scheme (dealt with in Report #25) and a number of small hydro schemes. The plant is part of the unified electrical transmission system for England and Wales. The demand on the system varies from about 10 GW (early morning on a Sunday in midsummer) to about 45 GW (mid-evening on a winter weekday). Typical variation in demand during a 24-hour period could be up to 20 GW, and the demand curve has been known to climb at a very high rate. The system is interconnected with the Scottish system and, by one line with the French system.

The owner and operator, the Central Electricity Generating Board has a statutory obligation to maintain system frequency between 49.5 Hz and 50.5 Hz, and this and the major variations in demand were part of the criteria in sizing, designing, and operating the plant. Other criteria were a result of operational experience at Ffestiniog.

The upper reservoir is formed in a glacially carved valley by a 2000-foot long dam. The dam, formed of waste rockfill and overburden from an abandoned slate quarry, together with newly quarried rock, has an upstream, single layer asphaltic concrete membrane. The height of the dam above ground level is 118 feet, and total height from the crest to the toe gallery trench is 226 feet. Water is conducted through the concrete headworks (with special antivortex screens) through a nearly horizontal 34'-5" diameter low pressure tunnel 5560 feet long to a surge pond. Below the surge pond is a 32'-10", 1453-foot long concrete lined shaft connected to a 31'-0" diameter high pressure tunnel and a concrete lined manifold. Six steel-lined weather conduits nearly 600 feet long enter the inlet valve gallery where there are weight operated spherical valves, which close in 20 seconds and open 5 seconds.

The powerhouse complex consists of the machine hall, 168 feet high, 77 feet wide, and 587 feet long, the transformer hall, main inlet valve gallery, draft tube valve gallery, busbar galleries, and starting equipment galleries, all tunneled in slate under an old abandoned slate quarry. There are three tailrace tunnels, daylighting through three gated tailrace structures. The lower reservoir is based on an existing lake slightly raised by the 13-foot high Afon y Bala Dam, and some of the old quarry workings.

The powerhouse contains six reversible pumped turbine units, each with a nameplate rating as follows:

	As Turbine	As Pump
Net Head	1757.42 ft	1787.6 ft
Output	317 MW	1766 cfs
Speed	500 rpm	500 rpm

Starting is by static AC frequency converter.

Of particular interest is the fact that the turbine and generators are connected by a long intermediate shaft, which can be removed for access to and removal of the runner within a spacious gallery without removal of the generator.

On the day of our visit, one machine was out of service for routine inspection and maintenance. We were able to examine the inside of the spiral case and distributor.

OPERATIONAL ASPECTS

The machines are operated in response to instructions from London which are given to the station as to which machine to put on and what mode it should be in. The units are operated as synchronous condensers in both pumping and generating directions.

There are very frequent mode changes at Dinorwig. For instance, on March 22, 1986, on Unit 1 there were forty mode changes in one 24-hour period, twelve of which required a circuit breaker operation. The definition of mode change adopted by the CEGB is simply of a change of operation of the unit, which does not necessarily mean a bringing it to rest and starting again. The units are normally set to govern the system with a droop setting of 1%. If the line frequency drops to 49.8 Hz, another unit is brought on line and the units are operated to equalize the time for each loaded automatically.

Maximum load on each unit is 330 MW generating. Minimum load is 90 MW. There is some rough running below this point and below 100 MW air is injected.

Overall efficiency so far is 78%. Efficiency is 76% based on energy in and out, not taking into account water level variations. This is a figure over a full year. They plan to perform a thermodynamic test to determine the turbine efficiency.

Over a one-month period, a typical generation figure would be 152,000 MWh, energy required for pumping would be 222,000 MWh, synchronous condensor would be 8000 MWh. The upper reservoir takes six hours pumping to fill.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

There are six shifts of six operators each. The shift comprises two engineers, three technicians, and one craftsman. In addition, there are 25 persons used for daily maintenance and a roving maintenance crew of ten. The maintenance inspection of Dinorwig is based largely on the anticipated fatigue life of the units and the associated crack propagation. As an example, the welds on the spiral case and intermediate penstocks are ultrasonically examined or "fingerprinted" every two years which takes three weeks. The examination is carried out with the welds scanned automatically and the results fed into the computer in the plant. Crack propagation predictions are made and repair work scheduled on the basis of those predictions. Other items of equipment are serviced on a preventive maintenance schedule and, as yet, there has been no major overhauls.

TURBINE PROBLEMS

The fatigue life of the units has been designed for 300,000 cycles. This represents 40 mode changes a day for 40 years.

There have been two thrust bearing failures on the first unit. It was found that the hydraulic down thrust was 300 tons giving a total downthrust of 800 tons. When starting, the operation staff did not admit water to the water-cooled shoes until 80% of speed was reduced which caused the shoes to deform and wipe. Modifications were made to the runner wearing rings, which reduced of the hydraulic downthrust to nearly zero, and to change from a tin-based white metal bearing to lead-based white metal. Bearing temperatures are now between 90° and 100°C. The pads were hand scraped to be slightly convex. Downthrust is increasing gradually; possibly because increasing the head cover pressure.

There was some cavitation damage on the stay vanes.

Some strange pock marking was observed on the wicket gates which occured when the machine was in spinning reserve mode. This apparently also occured at Ffestinog.

There is a sixth harmonic vibration caused by the runner passing the wicket gates during spinning reserve. The excessive vibration, necessitated that everything be restrained in this area, including the equalizing lines. There has been no cavitation damage so far to the equalizing lines. The equalizing lines are closed during the spinning mode.

The shaft seal was weight loaded for run-in. The weights were not covered for the regular operation which caused the seal to wear prematurely.

Rust deposits have been noticed in various pipes. The staff are concerned that this might be occurring in the bearing pads in areas of low cooling water velocity.

The equalizer line broke and was moved to run along the floor for better support.

GENERATOR PROBLEMS

There are no wedge problems evident. They have springs, but a slightly different arrangement of springs than in the U.S. Generally, the staff feel that Units 5 and 6 will have to be rewedged before 10 years is completed.

With the first four generators there has been a problem of high temperatures in the stator. The Roebel transposition of the windings wasn't done properly and the end turns were improperly connected. This allowed about 1 MW of circulating power. These units have the end turn connections corrected, but the transposition is still wrong. The transposition on the other units is correct, but they all still run hot. The staff are putting in capacitor couplings to monitor more closely. Also, they are considering modifying the air flow around the generator.

The first four units have had some corona damage and the last two units have suffered even more corona damage.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

The 18 kV unit circuit breakers suffer from pitting on the contacts. The main problems were the auxiliary switches. There has been no real problem with the SF_6 400 kV switchgear, although there was one flashover during commissioning.

There was galling in the spherical valve operating cylinder which had stainless steel parts rubbing together in relative motion. The cylinder was sleeved with bronze to correct this problem.

COMENTS AND IDEAS

There are only two points that the staff brought out as being worthy of consideration. Generally they are very happy with the plant as it is but they do feel that all junction boxes in the pump/turbine area should be waterproofed and secondly that there should not be so many caverns in the powerhouse structure. They feel that the arrangement with the numerous caverns leads to complicated operation.

ELECTRIC POWER RESEARCH INSTITUTE
HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-26 - FFESTINIOG

VISIT DATE - 2 APRIL 1986

OWNER: Central Electricity Generating Board (CEGB)

OWNER'S REPRESENTATIVES:

Colin Smith	- Maintenance Supervisor
Keith Thomas	- Planning Engineer
John Powell Jones	- Operator

EPRI REPRESENTATIVES:

A. Ferreira	- EPRI	- Coordinator
B. E. Sadden	- MKE	- Civil Engineer
J. L. Carson	- MKE	- Mechanical Engineer
W. R. Moon	- MKE	- Electrical Engineer

GENERAL AND PLANT DESCRIPTION

Ffestiniog was the first pumped storage scheme developed by the Central Electricity Generating Board. It is the only pumped storage scheme visited that has a separate pump and turbine. Ffestiniog went into operation in 1961 and since then has been used considerably more than originally intended.

Ffestiniog upper reservoir is formed by a concrete dam and is connected to the powerhouse by two concrete-lined tunnels and buried steel penstocks. The powerhouse is an indoor structure and discharges into a lower reservoir formed by a concrete dam.

The powerhouse contains four Francis turbines and centrifugal pumps with synchronous generators-motor each rated as follows:

	As Turbine	As Pump
Rated Head	925-1020 ft	1000 ft
Output	78 MW	745 cfs
Speed	428 rpm	428 rpm

OPERATIONAL ASPECTS

The units are always operating as a spinning reserve, generating or pumping and shutting down only when changing from pumping to generating. A unit is automatically loaded if the system frequency drops. Usually the plant pumps all night. Other than that, each operation rarely lasts for more than two hours. The reservoir is always full by 6:00 a.m. The units are block loaded when generating at 90 MW per unit, although the rated output is 75 MW. The energy ratio of generating to pumping is 0.7.

Unlike Dinorwig, the Ffestiniog operators choose which machines to use. The sequence of operation is such that units are operated to equalize the time on each.

The pumps are started by the turbine, after which the turbine inlet valve is closed and the turbine blown down. Brakes are applied at 25% speed.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

The first major overhaul was in 1985 after 25 years of operation. The overhaul of Unit 1 took 44 weeks.

The machines are inspected every year for two to three weeks. Cavitation repairs are performed only on the pumps about once every five years, but probably could be left for a period of five to seven years. After 25 years, some cavitation repair has been performed on one turbine, but the quantity was not measured. The valves are dismantled at this time.

During the annual inspection, brushes are cleaned, guide vanes are inspected, wearing rings clearances checked, and pumps and pipelines inspected. Minor maintenance work is also carried out. Oil is purified once a month with the unit operating. This year, for example, asbestos brake pads were replaced.

Operating staff consists of four operators for three shifts. The maintenance staff consists of four staff engineers and 12 maintenance operators. For major work, the operating staff call in the central maintenance group. They also have O&M responsibility for two 24 MW and one 6 MW plants using the crew mentioned above.

Forced outages have been limited to occasional problems with the inlet valve seals and control system faults. A number of earlier forced outages were caused by ground faults on the generator.

TURBINE AND PUMP PROBLEMS

The wicket gates have distinct dents on the side facing the runner which have not been explained. One unit vibrated a little during commissioning. After a few years, during an inspection, staff found that the headcover on this unit was tilted. There was also a slight guide vane rattle at the spinning reserve operation. The unit with the headcover problem has more rattle than the others. Originally, the wicket gate did not quite close properly, which probably contributes to the guide vane rattle. The governor was modified and closing the gates reduced the rattle but it is still present.

All embedded pipe that could be pressure tested has been and has been found to be satisfactory.

The pump bleed-off pipe corroded and was replaced with one connected to the turbine draft tube.

The turbine facing plates were steel with stainless cladding. During the overhaul, the cladding was found to be coming loose.

GENERATOR PROBLEMS

There were two bearing failures. Following these failures, the thrust pads were redesigned and a high pressure lift system installed. Four years later, another thrust bearing failed. The bearing pads are changed every four years now.

The units were originally designed for a 75 MW output. They units were later uprated to 90 MW and operated that way for 13 years, at which time the generators were rewound and uprated. The basic method of operation was to increase the rate of cooling and the cooling system efficiency. When the generators were rewound, the stators were removed and the rotors were left in place to avoid realignment.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

The switchgear was not designed for spinning reserve operation. There have been many more mode changes than planned. The oil in the units circuit breakers has to be changed every 360 operations. The breakers are now obsolete, but CEGB has found some similar breakers at the older power stations, so they have a stock of spares. The design life of a breaker is 2000 operations and they are now up to 28,000 on theirs. Nevertheless, during repair the circuit breakers are never out of operation for more than two days.

There were some signs of overheating of the transformers in 1965. A stripdown was performed but no repair work. One transformer exploded later due to water getting into the high voltage bushings. This resulted in high pressure in the tank which ruptured a low voltage bushing. There was no damage to the windings.

The hood of the pressure regulator valve vibrated and corroded. It was changed to stainless steel.

There is a continuing problem with the seals of the turbine inlet and pump discharge valves. Guard valve seals failed and had to be replaced fairly often.

CONTINUING CIVIL AND HYDRAULIC PROBLEMS

There has been some leakage around the spiral case; presumably through the concrete joints. Painting of the draft tube with epoxy is being considered.

The majority of the tunnels are steel lined. The shaft, however, has been repaired twice in 25 years. Most of the concrete problems in the shafts is thought to result because of poor construction and/or a bad concrete mix. The problems are centered around the voids behind the shaft lining and the spalling of some of the shaft lining concrete.

During early stages of operation the floating peat islands were somewhat of a problem, requiring frequent trashracks clean-ups. A log boom was installed to alleviate this situation. With time, the islands disintegrated and the problem solved itself.

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HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-27 - TURLOUGH HILL

VISIT DATE - 3 APRIL 1986

OWNER: Electricity Supply Board of Ireland

OWNER'S REPRESENTATIVES:

Peter Mulville	- Project Manager
Gerry McMahon	- Planning & Development Engineer
Pat Carey	- Technical Officer
John Godden	- Acting Plant Manager & Civil Engineer
John Byrne	- Electrical Engineer
M. G. Fitzpatrick	- Mechanical Design Engineer
Denis O'Mahoney	- Operation Superintendent

EPRI REPRESENTATIVES:

A. Ferreira	- EPRI	- Coordinator
B. E. Sadden	- MKE	- Civil Engineer
J. L. Carson	- MKE	- Mechanical Engineer
W. R. Moon	- MKE	- Electrical Engineer

GENERAL AND PLANT DESCRIPTION

Turlough Hill is the only pumped storage scheme in the system which serves the island of Ireland. The Irish system has peak demand of 2100 MW and a base demand of 900 MW. Since the interconnection between Northern Ireland and the Republic of Ireland was severed, the Irish system has been isolated, which is a rather special case.

The Turlough Hill powerhouse is underground. It contains four Francis pump/turbines and synchronous generators/motor, each rated as follows:

	As Turbine	As Pump
Rated Head	941 ft	943 ft
Output	73 MW	781 cfs
Speed	500 rpm	500 rpm

The first unit was commissioned in November, 1973 and the last in June 1974.

There is an intermediate shaft between the pump/turbine and generator, and a wide access passage with a crane which allows dismantling of the pump/turbine without removing the generator/motor rotor.

There is a permanent pump used to fill the penstock. This pump has two runners - one to operate as a pump to fill the line and one to serve as a generator for station service.

On the day that we were visiting the plant, no unit maintenance was being undertaken. Unit 1 was stopped, Units 2 and 3 were generating at 5 MW, and Unit 4 was generating at 50 MW.

OPERATIONAL ASPECTS

Turlough Hill units are dispatched from Dublin and the system dispatcher allows the plant operators to decide which unit should be put on line. Generally, the plant is required to generate from 8:00 a.m. to 12:00 midnight with two peaks, and to pump from midnight to 8:00 a.m. The upper reservoir is refilled every day, which represents a total of six hours pumping at full discharge. If the system frequency falls to 49.6, 49.4, 49.2, 49.0 Hz, respectively, an automatic starting sequence brings the units (as generators) up to a preset, usually full, load. Joint control facilities are available for sharing the load equally between units. When pumping, the units are disconnected at the same frequencies in sequence. An additional response to falling frequency has been provided for units already running in minimum generation mode. Two such units will rise to full load if the frequency falls to 49.8 Hz, with the other two units responding at 49.75 Hz. Under the present scheme, much of the time two units are running at 5 MW to allow for quick response to a falling system frequency.

The machines are designed to operate as synchronous condensors and originally they performed in this mode with the main inlet valve closed. Such an arrangement meant that some time lapsed before the machines could be put on line since the valves take 55 seconds to open. In 1978, the operation was modified to leave the valve open during synchronous condensor (turbine) operation. This improved the unit response time to three seconds but raised the power consumption from 1.5 MW to 4.75 MW during synchronous condensor operation. The mode was used extensively in 1980 to 1985, but because of the system operation change, was discontinued.

An extremely fast response time is imposed on the plant. A one-second response to the system can be obtained using what they call minimum generating. This involves running the turbine at 5 MW (aproximately) with the wicket gates cracked open slightly. This is not a very efficient way to run the machine and the plant staff think that the cheapest option would be for a thermal plant to pick up the load from one second to say four seconds with Turlough Hill picking up a load from their synchronous condensor mode in the generating direction. At present, the operating staff are investigating this mode of operation. During operation at minimum generation, air is injected directly into the draft tube and running the machines between 10 MW and 40 MW, which is very rough, is avoided.

Normally only two machines are run on minimum generation, one in each civil block.

During the night, usually three machines are pumping but sometimes four are used. Pumping is at a fixed gate of 70%.

Maximum plant efficiency is approximately 75%. However, last year (1985-86, March-March) an efficiency of 61.5% was achieved reflecting the fact that there was a lot of generation at minimum output.

Braking is dynamic (electric), with mechanical brakes used only in case of emergency.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

Plant operations management consists of four engineers: a station manager, an operations superintendent, a maintenance superintendent and a planning and development engineer. For the plant operating staff, on each shift there is one shift supervisor, one operator and one plant attendant, making a total shift staff of fourteen. In addition, there are about 30 other personnel on daily maintenance, including six mechanical tradesmen, six electrical tradesmen, two civil tradesmen, and three supervisors. All personnel are part of the group which, in addition to Turlough Hill, maintains one 30 MW hydro plant and two 4 MW hydro plants.

The maintenance intervals for different items within the plant vary. However, there is an annual inspection when the station is shut down for a couple of days during the low power demand, usually during the August bank holiday, which is a three-day weekend. The station downtime is used to check station protection, fire protection, switchyard, intake gate, tailrace tunnel, flap gates, and other items common to all units which could not be attended to otherwise. Each unit is

inspected each year, which normally takes one week, with a longer outage roughly every second year.

There is a five-year inspection of the penstock shaft and a separate annual inspection of the upper reservoir in June when daylight is available during low water levels without disturbing the normal operational cycle.

The one-week outage is basically for inspection. As far as the units are concerned, the generator and turbine are inspected, with the turbine inspected throughout. There is normally some cavitation damage repair required at the low pressure side of the runner buckets. No other significant cavitation damage occurs. In addition, the wicket gates almost always need adjustment, which can be time consuming.

From April 1985 to March 1986, failure to change mode occurred in 0.34% of the cases. The goal is to achieve a 0.25% failure rate. The plant availability in 1985 to 1986 was 98.2%. The total availability in 1984 to 1985 was 86%. The total availability in 1983 to 1984 was 92%. All the above figures include outages. In 1984 to 1985, the plant efficiency was 63%. In 1983 to 1984, the plant efficiency was 66%.

The preventive maintenance scheme is prepared by one person who takes input from the hours each item of equipment operates to prepare a preventive maintenance schedule. He also receives input from operators regarding the trends of various temperature readouts, etc. There is a weekly maintenance meeting to plan the maintenance scheduling.

TURBINE PROBLEMS

The wicket gates are fabricated of stainless steel between stainless steel facing plates. This resulted in early problems of the rubbing of the gates on the facing plates. The top and bottom clearances were increased and new seals added on the wicket gates and the facing plates.

Cavitation damage occurs only at the low pressure side of the runner buckets and is repaired every year. Units 3 and 4 have more cavitation damage. KMW, the manufacturer, did some reprofiling on Unit 4.

Runner sealing rings were wiped because of loss of cooling water on one unit. The staff have now installed proximity monitors with alarm and trip facilities.

There has been some damage to the wicket gates similar to that at Dinorwig, i.e., some pitting on the inside gate surfaces. The staff have found parts of bolts in the tailrace tunnel that had been passed through the runner.

The largely inefficient method of air injection for blowdown into the draft tube from the sides has been modified to include a "trombone" which directs the air directly to the center of the draft tube. This has made for the more efficient and effective air entry.

GENERATOR PROBLEMS

The generators run hot so cooling water flows have been increased. The bearings operate at 70°C, which is also a little high but there have been no problems as a result.

The main problem with the generator has been the bracing blocks on the end winding of the stator which are showing signs of cracking due to their construction. Unit 3 bracing blocks have already been replaced by glass fiber solid blocks.

The original lubricating oil Shell Turbo T68 was changed to Turbo T46, which reduced the bearing losses by 45 kW.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

The control sequence to retract the stainless steel seals of the main inlet valve before opening the valve is not adequate. Therefore, when the valve opens, the seals are sometimes not retracted, which results in their scoring. In addition, the body of the valve is corroded where the stainless steel coating contacts the seals. At present, a spare valve is being purchased to allow sequential replacement and repair of the existing valves.

Prior to the circuit breaker manufacturer updating their maintenance schedule, some problems were encountered. The main trouble was the air blast fans. Circuit breaker spare parts are easy to obtain at the moment. The breakers are rated at 5000 amp, 1000 MVA.

One instance, during commissioning, of a disconnect in the dynamic braking system closing at the wrong time on rundown which burned out 17 generator coils.

There has been some vibration of the upstream cylinder gate because of the lack of restraint. At one point, the vibration caused a bolt to drop into the penstock and

pass through the turbine. When the gate was inspected, another bolt about to fall was found. A more effective bolt tightening and locking arrangement is now being used. The gate was normally inspected every five years, but now it is inspected more frequently because of these problems.

There has also been a failure of the studs holding the downstream trashracks in place. These apparently were not prestressed. Those left were tightened, and the plates drilled and tapped for new studs.

CONTINUING CIVIL AND HYDRAULIC PROBLEMS

The upper reservoir is lined with a bituminous membrane. There were some failures, particularly in the floor area on the initial sealing, but these have not been repeated. Occasional blisters in the membrane were dug out and resealed with the same material. Some repairs are carried out with a type of roofing mastic recommended by the contractor, but even with fiber fill, this material sags. The repaired areas have been covered with aluminum paint to lower the temperature, but the temperature lowering was not sufficient to prevent movement. From time to time, small blisters up to three inches in diameter are still appearing on the membrane.

There is some leakage through the powerhouse floor around the draft tube liner.

An interesting phenomenon occurred during a maintenance period when an operator used a radio in an open governor cubicle. The unit behaved strangely for some time before it was realized the radio was interfering with the unit controls.

COMMENTS AND IDEAS

There are a number of ideas the staff would incorporate were the plant to be built today. The first and foremost would be introduction of a faster load acceptance response. This is a major function of a pumped storage scheme in an isolated electrical system. Next would be to line the entire spherical valve seal operating chambers with stainless steel. The staff would install instrumentation to determine whether the seals in the spherical valves have released, a cylinder gate at the intake, a vibration monitoring system, and increased storage for blowdown air, which is now being implemented.

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HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-28 - LE TRUEL

VISIT DATE - 10 APRIL 1986

OWNER: Electricite de France (EDF)

OWNER'S REPRESENTATIVES:

Dr. F. Dauchel	- EDF
Mr. Devernay	- EDF
Mr. J. Catalan	- EDF
Mr. N. Roche	- EDF
Mr. P. Jarriand	- Neyrpic

EPRI REPRESENTATIVES:

A. Ferreira	- EPRI - Coordinator
B. E. Sadden	- MKE - Civil Engineer
J. L. Carson	- MKE - Mechanical Engineer
W. R. Moon	- MKE - Electrical Engineer

GENERAL AND PLANT DESCRIPTION

Le Truel is an experimental unit and is the first 2-stage pump turbine in the world in commercial operation to have wicket gates on both stages. It was constructed as a joint experiement between EDF and Neyrpic in Grenoble. It was installed at an existing power station called Le Pouget.

The machine was designed and manufactured as a prototype to predict behavior, transients, etc. of a 300MW, 1000 meter head machine and the design requirements of the larger machine were followed. Many of the principles included in this machine are learned from La Coche, a five stage pump-storage plant.

The Le Truel unit is rated as follows:

	As Turbine	As Pump
Net Head	1443 ft	1427 ft
Output	38 MW	244 cfs
Speed	750 rpm	750 rpm

OPERATIONAL ASPECTS

The machine, although built as an experimental unit, is actually used in normal service. The experience total to March 1985 was 277 hours pumping and 330 hours generating. Total experience to March 1986 is 1522 hours pumping and 937 generating. It is expected that this discrepancy between pumping and generating will continue to increase.

The machine is started back-to-back in the pumping mode using the Pelton turbine of the existing Le Pouget power plant with the unit fully watered, although it can be started with the tailwater depressed. Starting the larger unit will be with the tailwater depressed. In this machine, air can be blown between the stages and below the runners.

Operation as a synchronous condenser was tested but this is not normal operation.

Generation can be performed between 15% and 100% of full load and the operators report that there is definitely less instability and vibration in this two-stage unit as compared with a single-stage unit.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

In general, EDF has found that removal of the stages of a multi-staged unit from above is quite difficult, particularly for runner removal. La Coche was therefore designed to remove the lower stage through the bottom of the unit because it is the one which suffers the worst cavitation damage. Even so, at La Coche EDF found themselves doing a lot of disassembly accessing the unit from above. For Le Truel, the unit can be dismantled from below with the rotating parts supported by the generator jacks.

One visual inspection was made in March 1985 and no cavitation damage was found. In general, no EDF machines are dismantled unless necessary, but are inspected for two weeks every year. At that time, if required, cavitation repair is carried out.

It is expected that the pressure on the bearing pads will be lower than normal and that the temperature rise will be no worse than the normal reversible pump turbine. Overall, the operators expect less maintenance in the two-stage unit than for a single reversible unit.

The runner may well need significant maintenance because of the very small clearance of the runner and seals. Runner radial clearances are, in fact, 0.70 mm for the labyrinth seal ring and 0.35 mm for the leakage joints.

TURBINE PROBLEMS

None.

GENERATOR PROBLEMS

None.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

None.

PAPERS

1. S. Casacci, N. Roche and P. Jarriand, "High-Head Pump-Turbines: French Experience," Water Power and Dam Construction, February 1983.

2. N. Roche, D. Lefevre, P. Robert, P. Jarriand, J. Rondot and B. Lourdeaux, "Tests on a French Adjustable Two-Stage Pump-Turbine," Water Power and Dam Construction, June 1985.

ELECTRIC POWER RESEARCH INSTITUTE
HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-29 - MONTEZIC

VISIT DATE - 11 APRIL 1986

OWNER: Electricite de France (EDF)

OWNER'S REPRESENTATIVES:

Pierre Cahuzac	- EDF
Maurice Virieux	- EDF
Andre Bergeret	- EDF
Mr. Chousseau	- EDF
Mr. Catalan	- EDF
Dr. F. Dauchel	- EDF
Mr. P. Jarriand	- Neyrpic

EPRI REPRESENTATIVES:

A. Ferreira	- EPRI	- Coordinator
B. E. Sadden	- MKE	- Civil Engineer
J. L. Carson	- MKE	- Mechanical Engineer
W. R. Moon	- MKE	- Electrical Engineer

GENERAL AND PLANT DESCRIPTION

The Montezic plant is underground and contains four pump-turbines, each rated as follows:

	As Turbine	As Pump
Rated Head	1367 ft	1400 ft
Output	228 MW	1512 cfs
Speed	428 rpm	428 rpm

OPERATIONAL ASPECTS

The minimum outputs of each unit at Montezic is 110 MW. The rated output is 230 MW, but it can be used up to 250 MW. Below 110 MW, the efficiency is low but the operators feel that the turbines could be used below this output without damage.

Pumping is performed with two different fixed gate openings and as the head changes there is an automatic change the settings. The settings are 60% and 55%.

The machines can operate as synchronous condensers in both directions of rotation.

There are approximately 1100 circuit breaker operations per year per unit. (Close and open are counted as one operation.)

The use of Montezic is rapidly increasing as shown below.

Operation	1983 Jan - Dec	1984 Jan - Dec	1985 Jan - May
Generate	1365	2024	838
Pump	935	1518	677
Synchronous Condense	808	776	336
TOTAL	3108	4318	1851
Average per Month	254	360	370

The efficiency that has been achieved at Montezic is 76% without auxiliaries or 75% including auxiliaries. Availability including forced outages and maintenance is exceptional. The staff consider that for a year, 92% would be a reasonable figure and quoted November 1985 to March 1986 when there were only two hours forced outage.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

Maintenance on the unit is carried out according to the EDF maintenance philosophy. For any equipment item, the number of times that maintenance is required or the number of pieces of equipment which have to be maintained for that major item, are plotted against time. This graph usually shows a large amount of maintenance while the machine is new, dropping very quickly to a low level of maintenance. When the unit is older, it will show an increase in the amount of maintenance. Major overhaul is proposed at this point.

The aforementioned maintenance approach is supplemented by an examination of each unit at Montezic for four weeks per year per machine. The operating staff expect this period to be shortened to three because at present this inspection is only performed on day shifts and it is thought that some night shift time will be used as well, thereby shortening the inspection time.

A complete check of vibration is done during the first years of the machine operation. This check is repeated after any partial or complete dismantling of the machine. Also, the vibration is checked at five-year intervals.

It is expected that in the overall scheme, no dismantling will be carried out until some major forced outage occurs or until clearances or vibration and noise increase or cavitation increases in line with the graph of parameters described above.

The upper reservoir has never been drained the unwatering but is planned in 1988. The maintenance crew consists of five electricians and seven mechanics on one shift.

TURBINE PROBLEMS

None.

GENERATOR PROBLEMS

On the rotor of one unit, spacers between the pole windings and the next pole winding came loose. These spacers were replaced and this corrected the problem. The spacers were then replaced on the other three units.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

There have been no problems in the ancillary equipment during the first four years of operation.

CONTINUING CIVIL AND HYDRAULIC PROBLEMS

Generally, the civil works have been acceptable on this project, although there has been some leakage through the fault which runs close to the powerhouse in a subvertical direction and almost parallel with the powerhouse axis. The leakage occurred along the fault and around the penstock concrete lining so the appropriate penstock was drained and regrouted. It was also found that plugs in the concrete lining (which plugged the holes in which the forms were jacked) had fallen out as had the plugging of the grout holes. This affected some 1% of the holes. The concrete that had fallen out had entered the spiral case and may well have damaged the wicket gates in a similar manner as at Dinorwig, but this fact is by no means certain.

There has been some sloughing off of the slopes around the reservoir, but nothing serious that would require any maintenance.

COMMENTS AND IDEAS

If the design or operating team prepared a similar project, they would have included at least two tailrace tunnels to avoid having to close all units down while one tailrace is dewatered. Also, because there has been flooding of four of their powerhouses, including Le Truel, they are devising, if possible, a much better layout of tunnels to evacuate flood water and they would always include in the future oversized sump galleries.

PAPERS

1. A. Bergeret, P. Jarriand and G. Caillot, "France's Most Powerful Pumped-Storage Plant," Water Power and Dam Construction, April 1983.

ELECTRIC POWER RESEARCH INSTITUTE
HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-30 - BAJINA BASTA

VISIT DATE - 8 APRIL 1986

OWNER: Republic of Serbia

GUIDE: Prof. Stojan Sedmak - University of Belgrade

EPRI REPRESENTATIVES:

A. Ferreira	- EPRI	- Coordinator
B. E. Sadden	- MKE	- Civil Engineer
J. L. Carson	- MKE	- Mechanical Engineer
W. R. Moon	- MKE	- Electrical Engineer

GENERAL AND PLANT DESCRIPTION

The semi-outdoor powerhouse contains two Francis pump turbines and synchrounous generators motor rated as follows:

	As Turbine	As Pump
Rated Head	1819 ft	2038 ft (max) 1744 ft (min)
Output	294 MW	1296 cfs (at max H) 1794 cfs (at min H)
Speed	428.6 rpm	428.6 rpm

The powerhouse is located downstream of the existing Bajina Basta Dam and reservoir which serves as the lower reservoir for the Bajina Basta pumped storage development.

OPERATIONAL ASPECTS

Bajina Basta is loaded to meet the power requirements determined by the dispatch office in Belgrade. The plant generally is block loaded, but participates in frequency control 33 to 50 percent of the time, operating with a 4% speed droop.

Units can operate as generators within the load range from 50% to 100% for the whole range of the net heads. This characteristic was confirmed during commissioning.

The owner has limited minimum output to 200 MW for normal operation. There is a relative magnifying of vibration and unstable operation due to vortices in the draft tube present at outputs below 200 MW. Maximum output of units is limited to 100% (263,0 mm) of wicket gates opening from the minimum net head H_{min} = 497 m to the net head H = 574 and the gate limiter keeps the maximum output at 299 MW, up to the maximum net head.

Each machine operates at 428.6 rpm as a generator with a power factor of .95 and as a motor with a power factor of 1.0. Pumping is carried out at wicket gates opening between 70% and 90%, with automatic positioning of the gates to give optimum efficiency.

A normal operation mode is pumping from 12:00 p.m. to 6:00 a.m. and then generating in the morning and evening peaks.

There is no air admission to the turbine, either in pumping or generating modes.

The depression air system operates at 73-78 bars (1058-1131 psi) and the air tanks have capacity sufficient for two single machine starts with one hour required for tank refilling.

Starting is by back-to-back connection with the existing station units at Bajina Basta. Starting in the generating mode takes five minutes, including synchronization and loading. Switching from the pumping to generating mode takes between 10-1/2 and 11 minutes.

Units are not designed to operate as synchronous condensers. One unit has been tested to operate as synchronous condenser in the pump direction. According to the results of this test, the possibility of units for the operation as synchronous condenser has been found out in both modes, either in pumping or in generating direction. Existing control equipment will permit operation of the units as synchronous condensers, but this is not normal practice. Operation of the units as synchronous condensers in the generating mode would require some changes in the control system.

To stop the unit, dynamic braking is used at 50% speed and mechanical at 3% speed. High pressure oil pumps operate when the unit is operating.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

Both units came on line in November 1982 and after 1000 hours total operation per unit, initial cavitation damage was noticed on the pressure side of the turbine inlet. The manufacturer modified the inlet. At the next annual inspection, only minor grinding was needed and none since. All cavitation repair was done in situ.

Annual maintenance occupies one month per year, usually June. The key element is the tunnel inspection, which takes three to four weeks, so one unit is normally overhauled before the tunnel inspection is commenced, then the tunnel inspection is commenced when the second unit is shut down. By the time the tunnel inspection is complete, the first unit is ready to come on line again.

The manufacturer of the units anticipated major overhaul after five years of operation. However, according to present experience, major overhaul will take place after approximately ten years of operation.

There are two main operators plus two auxiliary operators for each of the three shifts. In addition, there are 30 maintenance workers to do the basic jobs. Other workers come onto the site to do specific jobs. Both hydropower plants, Bajina Basta pumped storage and the original conventional hydro plant at Bajina Basta, are operated from the same control room and maintained by the same personnel.

The upper and lower penstock and the tailrace are provided with three ultrasonic flow measuring devices to monitor relative difference of water flow and to protect the water passage between the surge tank and the lower inlet/outlet structure against a rupture of the penstocks or failure of a spherical valve. This flow measuring system has been calibrated in the factory. The owner intends to recalibrate this system on site, and after that to use one of the devices for monitoring of the efficiency.

Efficiency, four quadrant characteristics and cavitation characteristics of the pump/turbines were accepted during model tests. Index tests performed during commissioning of units measured of the outputs as function of wicket gates opening at three heads (H_{min} H_{av}; H_{max}) for the generating mode and measured of the motor input at the same heads. The owner intends, in the future, to carry out efficiency tests for the units on site.

TURBINE PROBLEMS

The inlet edge of the runner blades, in the turbine direction of rotation, was corrected as stated above.

Shaft seals on both units were replaced with newly designed seals. Cavitation has been noticed on the stay vanes.

GENERATOR PROBLEMS

It is too early to tell, but there have not been any problems with wedges or with corona damage so far, although there was some corona damage during start-up. Retying was required for some of the end turns. Thrust bearing springs and pads on both units had to be modified.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

There have been no problems with the ancillary systems since commissioning, although there were some during startup.

CONTINUING CIVIL AND HYDRAULIC PROBLEMS

Bajina Basta is one of the highest head single-stage pumped storage schemes in the world and the upper penstock with characteristic pxD = 3990 m-m is one of the largest in the world, and as such, considerable care has been taken with the penstock design and construction. As stated above, ultrasonic flowmeters are installed to monitor any relative change in the penstock flow. There is a butterfly valve at the inlet of the upper penstock and a flap gate at the inlet of the lower penstock for emergency closing if there is a major leak in the penstock or failure of a spherical valve.

Every year some grout injection and concrete packing is required in the tunnels as a result of the unfavorable geological conditions.

The powerhouse tilted after installation of the pump-turbines and the shafts had to be realigned. When the units are in operation, there is some vibration of the powerhouse and the installed equipment.

COMMENTS AND IDEAS

The main comments are related to the tunnel construction. The construction took more than three years and had been the critical scheduling problem.

The outlet to the existing dam was constructed behind a protective bulkhead below water level. Some leakage occurred and was dealt with by divers.

If the project were designed and constructed today, many improvements would be considered in the design. The high head has not generally been a problem, but the utility has no plans to implement a similar high head project, only the experience gained from this project would be utilized.

ELECTRIC POWER RESEARCH INSTITUTE
HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-31 - MINGHU

VISIT DATE - 24 JANUARY 1986

OWNER: Taipower

OWNER'S REPRESENTATIVES:

Kao Cheng-Yi	- Project Director
Pan Pin-Sen	- Deputy Project Director
Lin Feng Lin	- Deputy Project Director
Lin Yi	- Chief of Planning Division
Lee Ming Hsiung	- Head of Engineering Division
James S. C. Kuan	- Head of Technical Data Division

EPRI REPRESENTATIVES:

B. E. Sadden	- MKE - Civil Engineer
W. R. Moon	- MKE - Electrical Engineer

GENERAL AND PLANT DESCRIPTION

Minghu is the only pumped storage scheme operated by Taiwan Power. It is based on an existing reservoir called the Sun Moon Lake at the center part of the island. There is a second pumped storage scheme under construction that will also use this reservoir as an upper pool and the same valley for the lower pool, but will be slightly downstream of the Minghu plant. At the time of our visit, there was no major maintenance in progress.

The Minghu project features an underground powerhouse. The upper pool intake is connected to the powerhouse by twin 23-foot diameter tunnels approximately 7762 feet long, each with a surge tank. Each tunnel is concrete-lined over its entire length and provided with the slide gates and trashracks. First operation took place in 1984.

The powerhouse contains four Francis pump-turbines with synchronous motor-generators, each rated as follows:

	As Turbine	As Pump
Net Head	1016 ft	1070 ft
Output	250 MW	2896 cfs
Speed	300 rpm	300 rpm

OPERATIONAL ASPECTS

The Taiwan power system is based on nuclear power. Hydroelectric generation capacity, including pumped storage, constitutes 15% of total installed capacity.

It is a general rule at Minghu that as much pumping is carried out at night as possible. During the day, Minghu generates power at peaks just before lunch, at 2:00 to 4:00 p.m. (summertime), and then later in the evening using as many units as necessary. Every weeknight an attempt is made to fill the upper reservoir, but weekend pumping is usually required to accomplish this objective. This work regimen results in the use of machines for up to 22 hours per day. Occasionally, units operate as a synchronous condensers, but this is not common.

As an average, six mode changes a day are expected.

Pumps are operated at best efficiency. The operators have tried a ±10% setting variance from the best gate opening, but this did not result in better operation.

The plant is remotely operated. It can perform the following startups: generation from zero speed, four minutes to synchronization, and seven minutes to full load; pumping from zero speed, seven minutes to full load.

In general, the operators favor the operation of Unit 2 or Unit 3 because they do not have pony motors and have to be started by one of the other units.

The operating staff are going to try pumping and generating at the same time with the pumping and the generating units on separate penstocks. This practice is not being implemented at present, but was included in the design criteria.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

After 2000 hours of operation, the runners were inspected but no cavitation damage was observed. The runners are stainless steel in one piece and are painted. There is a slight abrasion of the paint in one area. As routine maintenance, it is proposed that the units be inspected after two years of operation and the tunnels

after five years. There is continuous monitoring of dam movement and the powerhouse cavern deformation.

TURBINE PROBLEMS

None.

GENERATOR PROBLEMS

There have been no generator problems to date. The units were inspected after two years of operation and there were no signs of corona or other damage.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

Twice there have been unit shutdowns due to electronic equipment failures. The cause of these failures has been determined and the problem has been corrected.

ELECTRIC POWER RESEARCH INSTITUTE
HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-32 - NUMAPPARA

VISIT DATE - 27 JANUARY 1986

OWNER: Electric Power Development Company, Ltd. (EPDC)

PLANT REPRESENTATIVES:

S. Enomoto	- Deputy Superintendent
Mr. Hosaka	- Chief Civil Engineer
Mr. Nomoto	- Manager

EPRI REPRESENTATIVES:

B. E. Sadden	- MKE - Civil Engineer
J. L. Carson	- MKE - Mechanical Engineer
W. R. Moon	- MKE - Electrical Engineer

EPDC REPRESENTATIVES:

T. Kidahashi	- Director
F. Osawa	- Electrical Engineer

GENERAL AND PLANT DESCRIPTION

Numappara is one of the highest head pumped storage schemes in the world, with a net head of 1568 feet. It is owned and operated by EPDC, a quasi-government organization whose chief function is to ensure that each Japanese utility can always meet its load demand. The owner has therefore invested heavily in pumped storage.

The Numappara powerhouse is located underground. The upper reservoir is connected to the powerhouse by a 20.6-foot diameter tunnel 4690 feet long trifurcated into three 11.8/7.9-foot diameter penstocks 2650 feet long. There is a surge tank at the junction. The intake is provided with trashracks only. There are three tailrace tunnels 1663 feet long with slide gates and trashracks at the outlet. Initial operation was carried out in 1973.

The powerhouse contains three Francis pump-turbines and synchronous generators-motor each with the following ratings:

	As Turbine	As Pump
Gross Head	1555 ft	1503/1732 ft
Output	230 MW	1766/989 cfs
Speed	375 rpm	375 rpm

OPERATIONAL ASPECTS

Numappara is block-loaded from the control center in Tokyo. Synchronous condenser capability is provided but not used. Typical operation is to generate during peak hours from 8:00 a.m. to 10:00 a.m. and from 6:00 p.m. throughout the evening on weekdays, and to pump nights and weekend as much time as possible to refill the upper reservoir. Generating output is between 140 and 225 MW. The station is unattended at night and there are no operators at the plant except when maintenance is being performed. The average annual generation is 199 GWh and the annual pumping energy required is 321 GWh, resulting in a pumping/generating ratio of 1.61.

Units 1 and 3 are started by pony motors. Unit 2 is started back-to-back. Brakes are applied at 13% of rated speed on the shutdown or a mode change.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

Unit inspection is annual and requires one week per unit. All the units were completely dismantled after five years of operation. They will be dismantled again ten years thereafter. The time used for dismantling was 75 days for Units 1 and 3 (which have pony motors) and 70 days for Unit 2, using a 15-man crew.

At the time of dismantling, some cavitation damage was noticed on the trailing edge of the wicket gates next to the stainless steel overlay. Also, corrosion of the wicket gates was observed, probably due to high oxygen content of the water. However, no corrosion was noticed on the runner (which is cast of 17-4 stainless steel) or in the scroll case.

The inside of the conduits was inspected once in five years. The visible portions of the equipment and civil works are inspected twice a year. The pump-turbine is unwatered and inspected every year.

Operation and maintenance of the station is carried out by the following personnel: one superintendent; three deputies; two civil engineers; five electrical engineers; one mechanical engineer; and six administrative staff. Additional 50 people are

temporarily employed from other parts of EDPC or from outside contractors during the major overhauls.

During the period of 1980-84, scheduled outages were 6.7% and unscheduled outages totaled 0.1%.

The basic EPDC inspection and maintenance requirements are attached.

TURBINE PROBLEMS

There have been no significant problems associated with the turbines other than corrosion of the wicket gates. The relatively short five-year interval between major overhauls is an EPDC requirement for all their plants.

GENERATOR PROBLEMS

The generators are very tall and at the top of the machine, an extra stiffener was built in. It was found that this stiffener was, in fact, too strong resulting in a temperature rise in the upper guide bearing. The stiffener was modified to lower its overall stiffness and the upper guide bearing temperature has dropped by 15%.

During each overhaul, the stators have been rewedged on each unit.

There has been a coil connection failure on Unit 1.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

Circuit breaker contacts had to be repaired after 10,000 uses but have been fairly reliable up to that time.

The original brake shoes were failing due to delamination. They are applied at 13% of speed with continuous breaking.

The spherical shutoff valves were overhauled and seats repaired after 10 years of operation. The overhaul required about six weeks per unit.

CONTINUING CIVIL AND HYDRAULIC PROBLEMS

Civil works problems have been restricted to some blistering of the asphaltic membrane lining in the upper reservoir in the first two years. There were about 20 to 30 cases of blistering, each one approximately one foot in diameter. They occurred

mainly in the upper part of the lining and there has been no recurrence of the same problem after repairs have been completed.

In the lower reservoir, there has been an occasional slope erosion due to wind-generated wave action. Although the EPDC is not responsible for the repairs to the dam, they take an interest in the remedial work since it may affect the performance of the pumped storage scheme.

ELECTRIC POWER RESEARCH INSTITUTE
HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-33 - SHINTOYONE

VISIT DATE - 28 JANUARY 1986

OWNER: Electric Power Development Company, Ltd. (EPDC)

PLANT REPRESENTATIVES:

Kazuhisa Uchiyama	- Manager, Sakuma Regional Office
Hiroshi Yamada	- Asst. Manager, Sakuma Regional Office
Mr. Bandou	- Asst. Manager of Civil Section, Sakuma Regional Office
Yukio Takesue	- Asst. Manager of Electrical Section, Sakuma Regional Office

EPRI REPRESENTATIVES:

B. E. Sadden	- MKE - Civil Engineer
J. L. Carson	- MKE - Mechanical Engineer
W. R. Moon	- MKE - Electrical Engineer

EPDC REPRESENTATIVE:

T. Kidahashi	- Director

GENERAL AND PLANT DESCRIPTION

The Shintoyone features an underground powerhouse containing five generating units. Two of the units operate at 50 Hz, two at 60 Hz, and one features dual frequency. There is a spherical shutoff valve at each unit, as well as slide gates and trash-racks at both reservoirs.

The Francis pump/turbines and synchronous generator/motor are rated as follows:

	As Turbine	As Pump
Rated Head	666 ft	590/ 804 ft
Output	230 MW	4341/2910 cfs
Speed - Units 1 & 5	250 rpm	250 rpm
Units 2 & 4	257 rpm	257 rpm
Unit 3	214/257 rpm	214/257 rpm

OPERATIONAL ASPECTS

The plant is remotely operated with no operators stationed at the plant.

Operating limits on the machine are 140 MW to 225 MW generating and 260 MW pumping. Gate opening during pumping is automatically varied to provide the best efficiency at the prevailing head.

This is an EPDC station and the machines are operated similarly to Numappara. Shintoyone can be operated as a synchronous condenser but is not.

No air is added during generation, but during pumping air is admitted to the draft tube at a transient stage, about 30% gate.

The operational modes at Shintoyone are as follows: start to synchronize and generate - three minutes plus another three minutes for the loading; pony motor start to pumping - eight minutes plus one-and-a-half minutes for the loading; back-to-back start to pumping - four minutes plus one-and-a-half minutes for the loading.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

All units have been overhauled once and Unit 5 is being overhauled a second time. Overhaul has taken between 60 and 100 days per unit.

The equipment access to the powerhouse is by a hoist down a shaft onto a trolley which is then hauled into the powerhouse proper to the area served by the powerhouse crane. According to the operators, this type of access to the powerhouse has added time required for some maintenance operations and to the construction time. As far as normal maintenance is concerned, operators consider the impact to be minimal to date.

There are 20 civil technicians, 35 electrical and mechanical technicians, including those required for switchyard work, and ten administrative personnel for O&M work. This crew operates and maintains eight power stations and the associated transmission systems.

TURBINE PROBLEMS

There has been some deflection of the bearing thrust pad and it has therefore been redesigned, made smaller and the spring rate has been changed on all the units.

As with all EPDC units, the wicket gate bearings have now been changed to greaseless.

There has been minor cavitation damage and repair performed on the outside diameter of the runner buckets.

GENERATOR PROBLEMS

There have been no generator problems apart from some minor wedge loosening.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

There have been no problems with ancillary electrical equipment.

CONTINUING CIVIL AND HYDRAULIC PROBLEMS

A continuing problem is the vibration of the draft tube trashracks. The staff could not tell us whether vibration is worse during generating or pumping. There is no particular trash problem in the lower reservoir, although in the upper reservoir trash has to be cleared from the screens at least three times per year.

ELECTRIC POWER RESEARCH INSTITUTE
HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-34 - MASEGAWA

VISIT DATE - 29 JANUARY 1986

OWNER: Chubu Power Company

OWNER'S REPRESENTATIVES:

Mr. Kamiya	- Chief of Plant
Mr. Kawai	- Electrical Engineer
M. Miyata	- Electrical Engineer
S. Tarumi	- Visitor Relations
S. Suto	- Civil Engineer

EPRI REPRESENTATIVES:

B. E. Sadden	- MKE - Civil Engineer
J. L. Carson	- MKE - Mechanical Engineer
W. R. Moon	- MKE - Electrical Engineer

EPDC REPRESENTATIVE:

Fumio Arakawa	- Manager, Power Engineering

GENERAL AND PLANT DESCRIPTION

The Masegawa powerhouse is located underground and contains two Deriaz pump turbines and synchronous generator/motors. There are no shutoff valves. The intake is adjustable for control of water quality. There are wheeled gates at the surge tank and trashracks at the intakes and draft tubes.

Each pump turbine is rated as follows:

	As Turbine	As Pump
Rated head	327 ft	360 ft
Output	149 MW	4719 cfs
Speed	180 rpm	180 rpm

OPERATIONAL ASPECTS

Masegawa is remotely controlled from a control center located 25 miles from the plant by means of two channels of a microwave link. The normal limits of generating output is between 50 and 144 MW. Pumping is from 100 to 160 MW which is automatically controlled at best efficiency for the prevailing head.

There are operating restrictions on Masegawa because of the requirement for irrigation water. During the months from May through February, the allowed range of the upper reservoir water level fluctuation is very limited since the low level storage is required for irrigation. In addition, there is a restriction on discharge during generation if there is a machine not operating in the power station immediately downstream. The plant can come up in three minutes from zero load to synchronous speed. Starting is performed with runner blades closed until the unit is synchronized.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

The maintenance crew at Masegawa are eight electrical engineers and nine civil engineers, all of which are Chubu personnel. Additional mechanical engineers and technicians from other plants are used as needed.

The turbine hydraulic passages are inspected every three years, requiring eight hours to dewater. The time of each inspection is approximately seven days and the units can be inspected separately because each has a separate penstock. Unit 2 was disassembled after ten years of operation. Overhaul required 110 days. Cavitation damage found on the suction side of the runner was quite deep. The ten-year period between inspections was an exception to the Chubu policy of a 12-year interval between disassembly of units and was chosen at first due to the fact that this is a Deriaz type unit. However, because there was no particular problem discovered at the first disassembly, future overhaul will be carried out at the 12-year interval, which is the maximum allowed.

The tunnels have not been inspected as yet; there are no plans for tunnel inspection.

The trashracks are inspected every 10 years and there is no evidence of any damage.

Every year there is an inspection of the upstream gates requiring six days for each gate and a total of 13 days for the whole plant.

TURBINE PROBLEMS

None.

GENERATOR PROBLEMS

None.

EQUIPMENT PROBLEMS

Even after 12 years of operation, there were no problems with the equipment.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEMS PROBLEMS

None.

CONTINUING CIVIL AND HYDRAULIC PROBLEMS

There is a leakage in the powerhouse cavern was very light and no grouting was required.

ELECTRIC POWER RESEARCH INSTITUTE
HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

FIELD REPORT B-35 - OKUYAHAGI PLANTS 1 & 2

VISIT DATE - 30 JANUARY 1986

OWNER: Chubu Power Company

OWNER'S REPRESENTATIVES:

Tsuyoshi Takehara - Manager of Plant (not at plant during visit)

EPRI REPRESENTATIVES:

B. E. Sadden	- MKE	- Civil Engineer
J. L. Carson	- MKE	- Mechanical Engineer
W. R. Moon	- MKE	- Electrical Engineer

EPDC REPRESENTATIVE:

Fumio Arakawa - EPDC - Manager, Power Engineering

GENERAL AND PLANT DESCRIPTION

The Okuyahagi projects consists of two plants in series with an intermediate reservoir along with normal upper and lower reservoirs.

The total capacity of both plants is 1095 MW and the equivalent capacity of the upper reservoir is 12 hours at full output.

From the upper reservoir, flow is conducted through a headrace tunnel and penstock, which incorporates a headrace surge tank.

The penstock is trifurcated just above Plant 1 powerhouse where three Francis reversible pump-turbines are installed.

After the point where the three draft tubes join together, there is a tailrace surge tank and a tailrace tunnel, which discharges to an intermediate pool.

The underground power station at Plant 2 is located between the intermediate and lower reservoir.

The hydraulic structures, which are similar to those for Plant 1 (since the maximum turbine flow is the same), consist of a headrace tunnel, a penstock, and a vertical shaft.

The penstock is trifurcated just above the Plant 2 power station.

Surge tanks are installed at the headrace and tailrace tunnel ends, as is the case for the Plant 1.

Plant 2 also has three Francis type reversible pump-turbines.

Each pump/turbine is rated as follows:

	Plant 1		Plant 2	
	As Turbine	As Pump	As Turbine	As Pump
Rated Head	529 ft	598 ft	1327 ft	1463 ft
Output	105 MW	2402 cfs	267 MW	1766 cfs
Speed	300 rpm	300 rpm	360 rpm	360 rpm

OPERATIONAL ASPECTS

Okuyahagi operates much as other pumped storage schemes in that it pumps at night and generates during the daily peaks. However, its operation is complicated by the three reservoirs and two powerhouses. The middle reservoir is sized so that it will compensate for the varying pumping rates between the two powerhouses. Essentially, with all units operating, the upper station pumps more than the lower so that during the pumping cycle, the middle reservoir gradually draws down. The middle reservoir has sufficient capacity for eight hours of such drawdown but if only one plant is operated at full discharge its capacity will be exceeded in less than one hour.

Operation of Plant 2 is controlled from the Plant 1 powerhouse. There is no requirement for the preferential starting of the units in either plant. Operating staff are more concerned about the control of the middle reservoir level, so if the intermediate reservoir is high, when pumping is required a unit in the upper power plant will be started, and if the intermediate reservoir is low, the lower plant will be started first. The reverse sequence is employed when generating. During the generation, the computer distributes the load between the stations based on the intermediate reservoir water level.

The units generate between 70 and 260 MW at Plant 2 and 30 MW to 105 MW at Plant 1. Parameters available to the computer to distribute the load are the water level in the middle reservoir, the static head from the upper to the middle reservoir, and the static head from the middle to the lower reservoir.

MAINTENANCE SCHEDULING, AVAILABILITY AND OUTAGES

The plants have been in operation for four years and planned outages over this time has been 16.8%. As yet, there have been no forced outages. Maintenance crew at Okuyahagi include 20 electrical and mechanical personnel and 11 civil personnel. The crew used at Okuyahagi is also used in eight other power plants.

TURBINE PROBLEMS

None.

GENERATOR PROBLEMS

None.

ANCILLARY MECHANICAL AND ELECTRICAL SYSTEM PROBLEMS

None.

CONTINUING CIVIL AND HYDRAULIC PROBLEMS

None.

Appendix C

MANUFACTURER VISIT REPORT

Appendix C consists of notes made during a visit to Allis-Chalmers.

ELECTRIC POWER RESEARCH INSTITUTE
HYDROELECTRIC PUMPED STORAGE DEVELOPMENT
CONSTRUCTION AND OPERATING EXPERIENCE

MANUFACTURER REPORT - ALLIS-CHALMERS

VISIT DATE - 30 MAY 1986

MANUFACTURER'S REPRESENTATIVE:

Richard Fisher - Manager, Applied Hydraulic Eng'g.

EPRI REPRESENTATIVE:

J. L. Carson - MKE Mechanical Engineer

DEVELOPMENTS

There have been significant advances in hydraulic design since 1980. These include:

- Cavitation prediction by computer analysis.
- Fatigue analysis using assumed cycle loadings.
- Fracture mechanics analysis based on assumed flaws.
- Shaft critical speed analysis using non-linear analysis and including bearing stiffness.
- Predictions of shaft displacement based on the determination of oil film thickness and thermal distortion of the bearings.

DESIGN AND MATERIALS

For heads above 500 feet, cavitation damage is likely if the setting is based on visual cavitation in the model, equivalent to an acoustic emission value of about 300.

There is only a small cost premium for 13-4 stainless steel as compared to mild steel with stainless overlay.

Stay vanes on high head units should be milled or formed. Flat plates may be used on low head units or where efficiency is not important. The loss is about 0.2%. Runner buckets should also be milled or formed for better homology with the model.

Some form of gate restraining should always be employed. From a design standpoint, Mr. Fisher likes individual servomotors, but they are prone to operating problems.

Hydraulic transients are determined digitally.

MODEL TESTS

- Efficiency tests should cover four quadrants.
- Cavitation performance should consider both visual and acoustic emission methods for determination of the model sigma.
- The model must be complete for all hydraulic passages from the spiral case inlet to the draft tube exit.
- Test data for the turbine mode should be collected at a high sigma and checked at the plant sigma.
- The performance in the pump mode is dependent on the sigma, and therefore tests should be made at the plant sigma.
- Transients cannot be modeled, including blowdown for pump starting. A-C has done blowdown tests but nothing useful was learned.
- The draft tube surge has been measured. It sometimes correlates to the prototype and sometimes not.

FIELD TESTS

Field tests are recommended for efficiency, balancing and hydraulic transients.

DISCUSSION OF PROBLEMS

The Bath County unit was operated with the runner drain valve closed. The wearing rings distorted and were wiped; replacement was necessary. The facing plate bolts came out.

The Fairfield runner outside diameter of buckets was reported reduced by 2-1/2 to 3 inches. Mr. Fisher explained that this was done to avoid an unstable range of operation.

Hydraulic transients may cause problems with power absorption when turbining at speed-no-load.

UPGRADING EXISTING UNITS

Because of the advances in hydraulic design since the 1970's, there is a good potential for upgrading existing pump-turbines. Some of the potential benefits are:

- Efficiency of new designs is better by up to 5%.
- Old designs did not model or take into account of the leakage. They also took the full Moody step-up, which may indicate efficiencies greater than actual.
- With new runner and wicket gates, an increase in efficiency of 3% to 4% is possible. Payback could be one to two years.

Appendix D

PROBLEM MATRIX

Appendix D summarizes those problems that are significant in either their magnitude or frequency, as reported by the plant operators.

FILE PLTDT998.WK1

PROBLEM MATRIX
TABLE 1

APPENDIX D
SHEET 1

NAME	RUNNERS GENERL	DIST. SEALS	SHAFT SEALS	DEPRESS SYSTEM	HEAD COVER/ STAY RINGS	BEARINGS	WICKET GATES	WEAR RINGS	VIBRATION -MAJOR	SPHERE VALVES	EQUAL. LINES	SHAFT	WEDGES	INSULATION	CORONA DAMAGE	GEN. COOLING
DOMESTIC PROJECTS																
BATH COUNTY	-	-	XXX	XXX	-	XXX	-	XXX	-	-	-	-	-	-	-	XXX
BEAR SWAMP	-	-	XXX	-	-	-	XXX	-	-	XXX	XXX	-	XXX	-	-	-
BLENHEIM GILBOA	-	XXX	-	-	-	-	XXX	-	XXX	XXX	XXX	-	XXX	-	XXX	-
CABIN CREEK	XXX	-	-	-	-	XXX	XXX	XXX	-	XXX	-	-	-	-	-	-
CARTERS	XXX	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CASTAIC	-	XXX	-	-	-	-	XXX	-	-	-	-	-	XXX	-	-	-
FAIRFIELD	-	-	XXX	-	-	-	XXX	-	-	-	-	-	XXX	-	-	-
HELMS	-	-	-	-	-	-	-	-	XXX	XXX	XXX	-	-	-	-	-
HORSE MESA	-	-	-	-	-	-	-	XXX	-	-	-	-	XXX	XXX	-	-
JOCASSEE	-	-	-	-	-	XXX	XXX	XXX	-	-	-	-	XXX	-	-	XXX
LEWISTON	XXX	-	-	-	-	-	XXX	-	-	-	-	-	-	-	-	-
LUDINGTON	XXX	-	-	-	-	-	XXX	XXX	-	-	-	-	XXX	-	XXX	-
MORMON FLAT	XXX	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MOUNT ELBERT	-	-	-	XXX	-	-	XXX	-	-	-	-	-	XXX	-	XXX	-
MUDDY RUN	XXX	-	-	-	-	-	-	XXX	-	-	-	-	XXX	-	XXX	-
NORTHFIELD MOUNTAIN	-	-	-	-	-	-	-	-	XXX	XXX	XXX	-	-	-	-	-
RACCOON MOUNTAIN	-	-	-	-	-	XXX	XXX	XXX	-	XXX	-	-	XXX	-	-	-
SALINA	-	-	-	-	-	-	XXX	XXX	-	-	-	-	XXX	-	-	-
SAN LUIS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	XXX	-
SENECA	XXX	XXX	-	-	-	-	-	-	-	XXX	-	XXX	-	-	XXX	-
SMITH MOUNTAIN	XXX	-	-	-	-	-	XXX	XXX	-	-	-	-	XXX	XXX	-	-
TAUM SAUK	XXX	-	-	-	-	-	-	XXX	-	XXX	-	-	XXX	-	-	-
WALLACE	-	-	-	-	-	XXX	XXX	XXX	-	-	-	-	XXX	-	-	-
YARDS CREEK	XXX	-	-	-	XXX	-	XXX	-	-	-	XXX	-	-	-	XXX	-
FOREIGN PROJECTS																
DINORWIG	-	-	-	-	-	XXX	XXX	-	-	XXX	-	-	XXX	-	XXX	-
FFESTINIOG	-	-	-	-	-	XXX	-	-	-	-	-	-	XXX	-	-	-
TURLOCH HILL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LE TRUEL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MONTEZIC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BAJINA BASTA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MINGHU	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NUMAPARRA	-	-	-	-	-	-	-	-	-	XXX	-	-	XXX	-	-	-
SHINTOYONE	-	-	-	-	-	-	-	-	-	-	-	-	XXX	-	-	-
MASEGAWA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OKUYAHAGI PLANT 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OKUYAHAGI PLANT 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

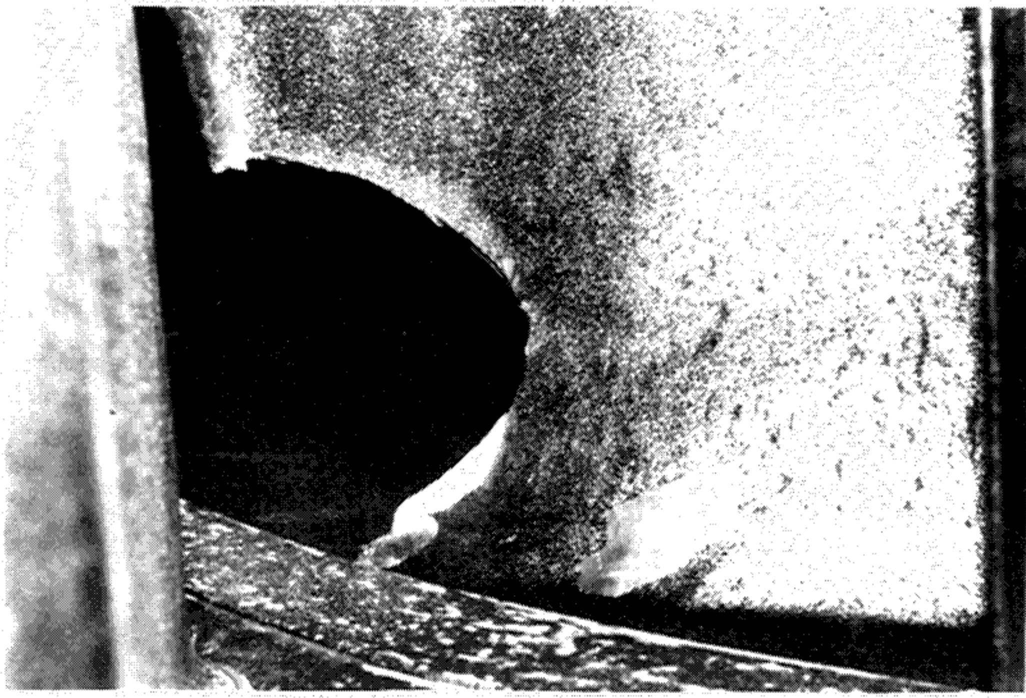
PROBLEM MATRIX
TABLE 2

NAME	START EQUIP	UNIT BREAKERS	STATOR REWIND	CONTROL SYSTEMS	TRANSFORMERS	UPPER RES. LEAKAGE	PENSTOCK	TUNNEL LINING	TRASHRACK	PHSE LEAKAGE	PHSE SIZE	SILT	FLOODING OR NEAR FLOODING	RESER. SLOPES	DAM PROBLEMS
DOMESTIC PROJECTS															
BATH COUNTY	-	-	-	-	XXX	-	XXX	-	-	-	-	-	-	-	-
BEAR SWAMP	-	-	-	-	-	-	-	-	-	-	XXX	-	-	-	-
BLENHEIM GILBOA	-	XXX	-	-	XXX	-	-	-	-	-	-	-	XXX	-	-
CABIN CREEK	-	XXX	-	-	-	-	-	-	-	-	-	-	-	-	-
CARTERS	-	XXX	-	XXX		-	-	-	-	-	-	-	-	-	-
CASTAIC	-	XXX	-	-	-	-	-	-	-	-	-	-	-	-	-
FAIRFIELD	-	XXX	-	-	XXX	-	XXX	-	XXX	XXX	-	-	-	-	-
HELMS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HORSE MESA	XXX	XXX	-	-	-	-	-	-	-	-	-	-	-	-	-
JOCASSEE	-	XXX	-	-	XXX	XXX	-	XXX	-	-	-	-	-	-	-
LEWISTON	-	XXX	XXX	-	-	-	-	-	-	-	-	-	-	-	-
LUDINGTON	-	-	-	XXX	XXX	-	-	-	-	-	-	-	-	-	-
MORMON FLAT	-	XXX	XXX	-	-	-	-	-	XXX	-	-	-	-	-	-
MOUNT ELBERT	XXX	XXX	-	-	-	-	-	-	-	-	-	-	XXX	-	-
MUDDY RUN	-	-	XXX	-	-	XXX	-	-	XXX	-	-	-	-	-	-
NORTHFIELD MOUNTAIN	-	XXX	-	-	-	-	-	-	-	-	XXX	XXX	XXX	-	-
RACCOON MOUNTAIN	-	-	-	-	XXX	-	-	-	-	-	XXX	XXX	XXX	-	-
SALINA	-	XXX	XXX	-	-	-	-	-	-	-	-	-	-	-	-
SAN LUIS	-	XXX	-	-	-	-	-	-	-	-	-	-	-	-	XXX
SENECA	-	XXX	XXX	-	-	XXX	-	XXX	-	-	-	-	-	-	-
SMITH MOUNTAIN	-	XXX	XXX	-	-	-	-	-	XXX	-	-	-	-	-	-
TAUM SAUK	-	-	-	-	-	XXX	XXX	-	-	-	-	-	-	-	-
WALLACE	-	XXX	-	-	-	-	-	-	-	-	-	-	-	-	-
YARDS CREEK	XXX	XXX	XXX	-	XXX	XXX	XXX	-	XXX	-	-	-	XXX	-	-
FOREIGN PROJECTS															
DINORWIG	-	-	-	-	XXX	-	-	-	-	-	-	-	-	-	-
FFESTINIOG	-	XXX	XXX	-	XXX	-	-	XXX	-	-	-	-	-	-	-
TURLOCH HILL	-	XXX	-	XXX	-	-	-	-	-	-	-	-	-	-	-
LE TRUEL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MONTEZIC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BAJINA BASTA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MINGHU	-	-	-	XXX	-	-	-	-	-	-	-	-	-	-	-
NUMAPARRA	-	-	-	-	-	XXX	-	-	-	-	-	-	-	-	-
SHINTOYONE	-	-	-	-	-	-	-	-	XXX	-	-	-	-	-	-
MASEGAWA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OKUYAHAGI PLANT 1	-	-	-	XXX	-	-	-	-	-	-	-	-	-	-	-
OKUYAHAGI PLANT 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix E

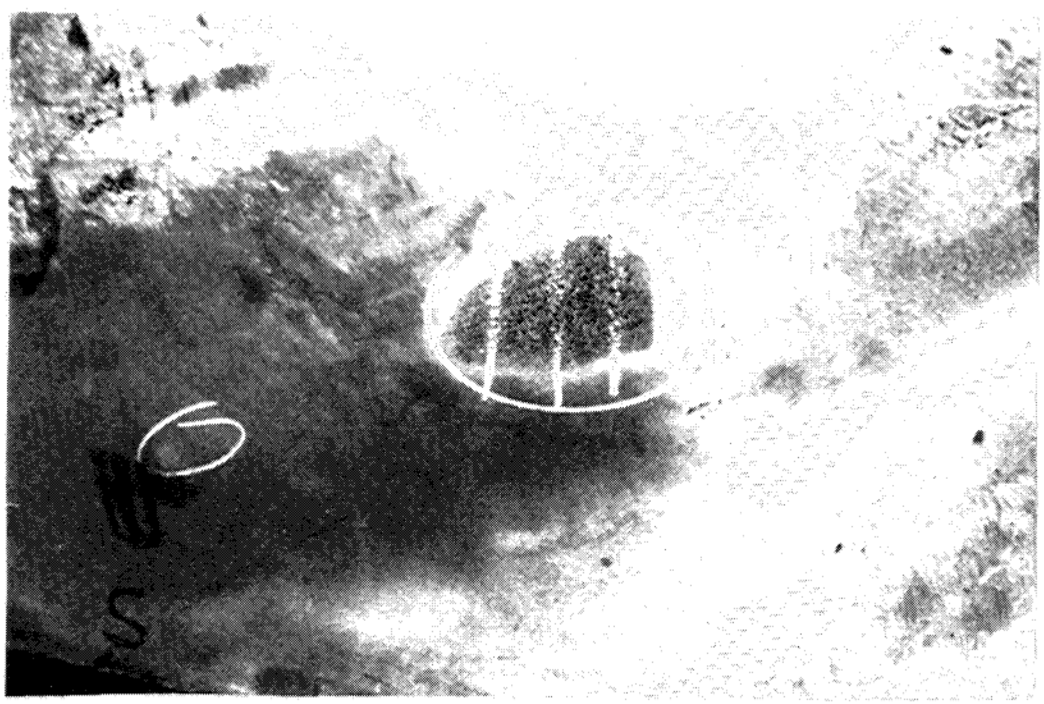
PHOTOGRAPHS

During the field visits, photographs were taken by the investigators. Of these, a few are included here as Appendix E to show problems that have been encountered, special features, and other interesting items.



MUDDY RUN

Cracking of the Runner Bucket

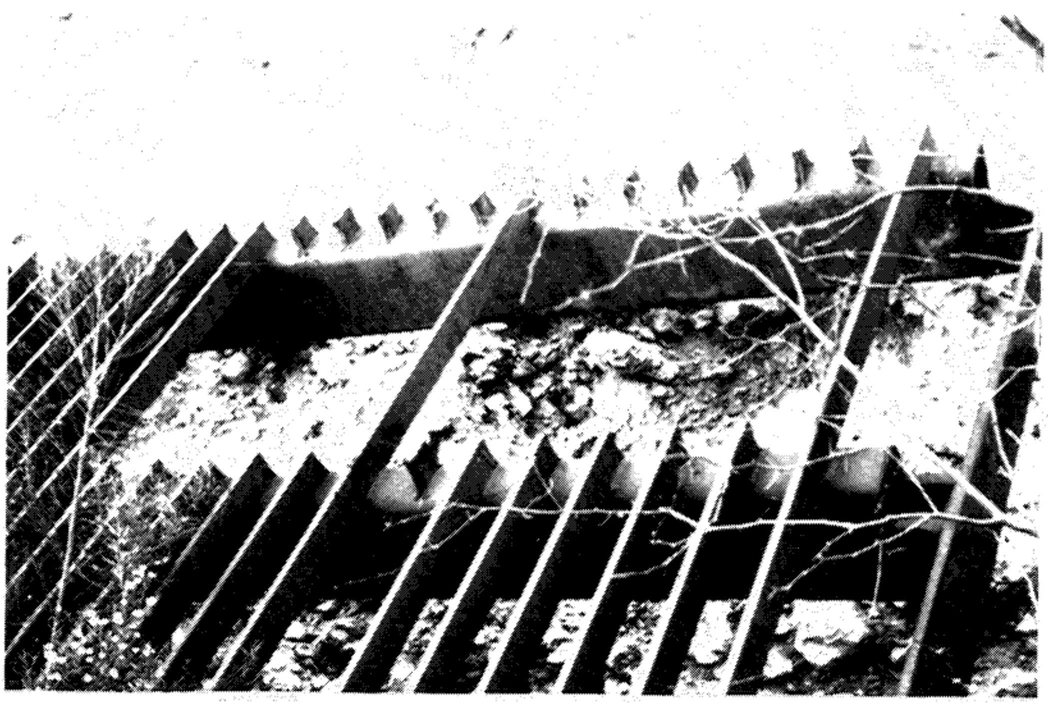


BEAR SWAMP

Cavitation on Suction Side of the Runner Bucket

FAIRFIELD

Floor Cracks in the Electrical Gallery

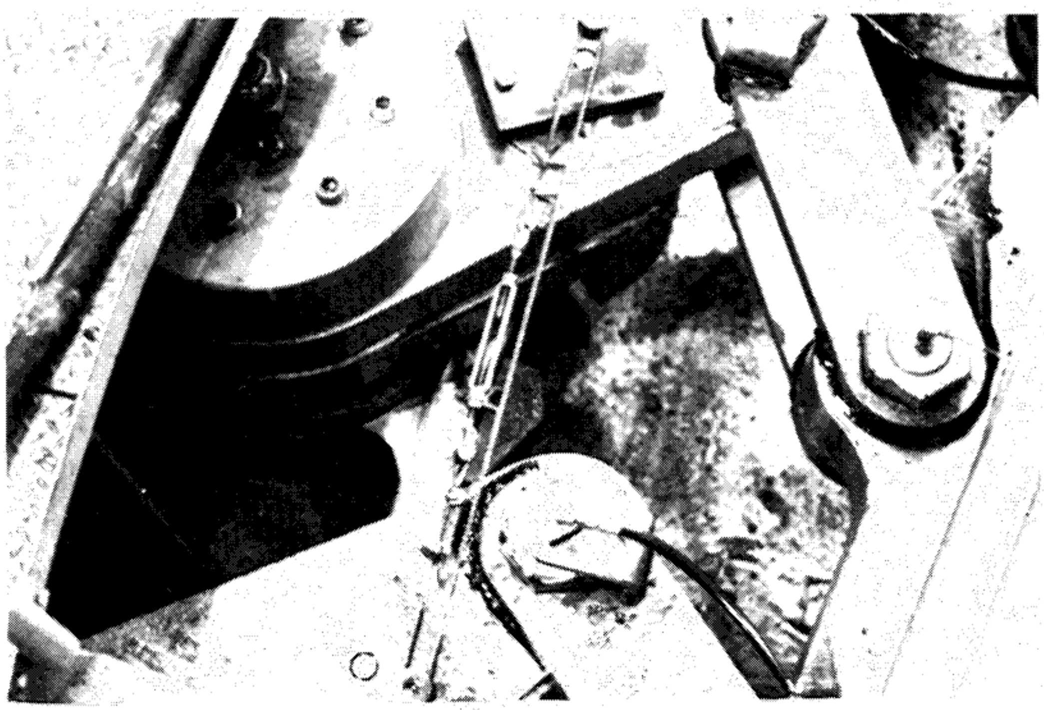


MORMON FLAT

Damaged Trashrack

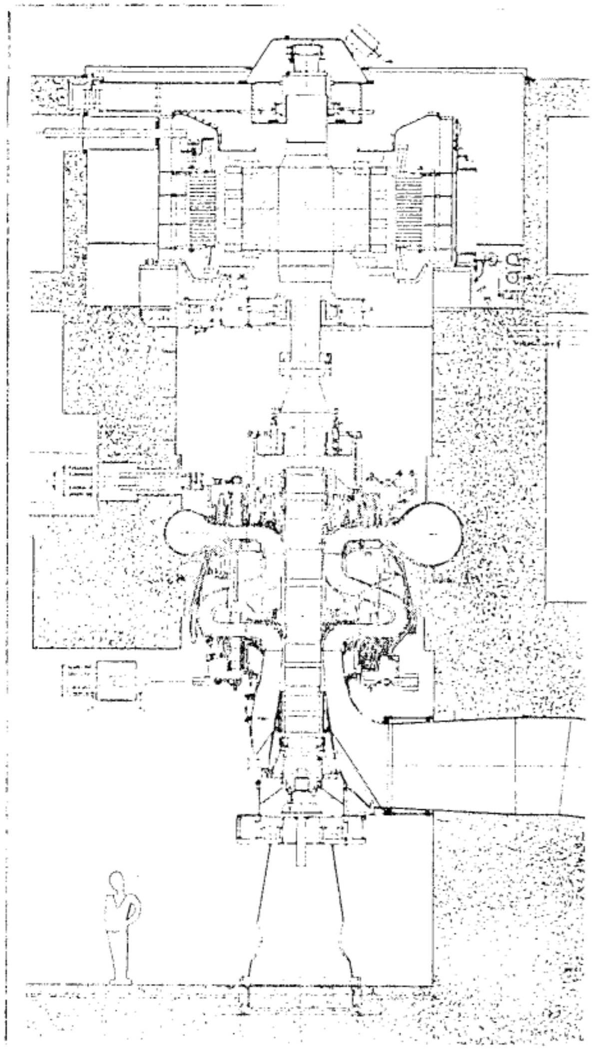
DINORWIG

Turbine Floor Showing Access to the Turbine Pit
and Sound Abating Housings



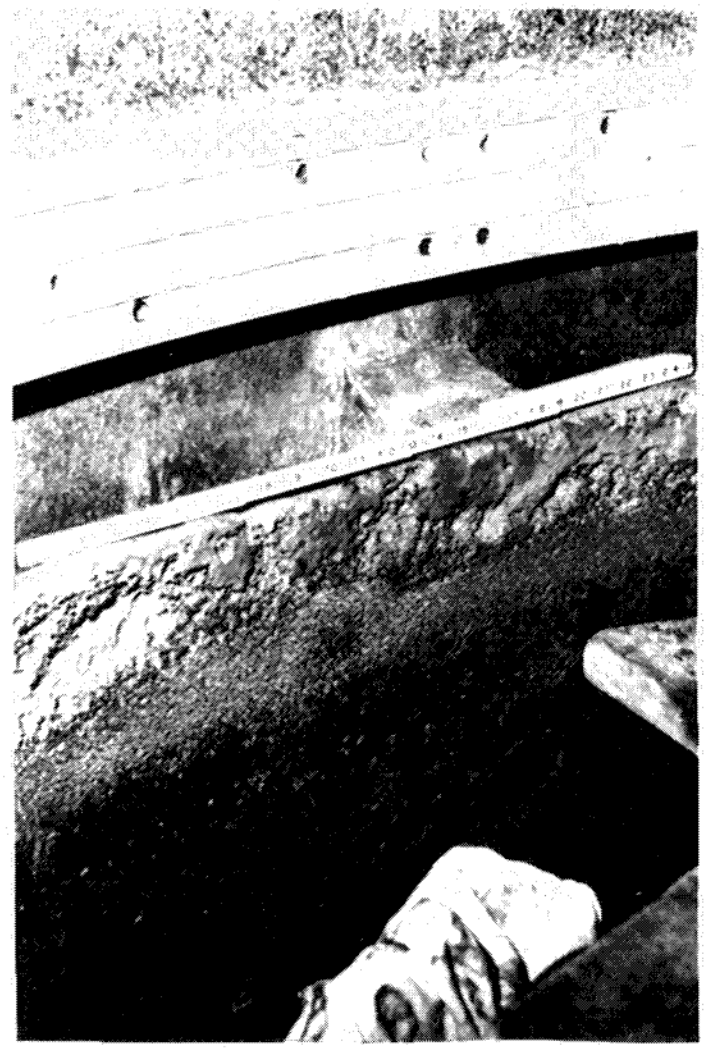
SENECA

Gate Mechanism with Cables to Reduce Wicket Gate Vibration



LE TRUEL

Cross Section of the Unit



MUDDY RUN

Cavitation Damage at Top of the Draft Tube Liner

Appendix F

SAMPLES OF MAINTENANCE CHECKLISTS

Two plants gave the investigators samples of maintenance documentation. The first sample is a completed checklist used at Blenheim-Gilboa for the 1981 annual maintenance of a unit. The second sample represents company procedure for maintenance of pumped storage plants under the control of Electric Power Development Company, Ltd. (EPDC) of Japan (translated from Japanese).

ANNUAL MAINTENANCE

UNIT #2

DATE 11-3-81

P\' filters were cleaned:
R. RKS: Clean filters installed.

Bolts, nuts, and hangers in the PMG were checked:
REMARKS: Found about 14 bolts loose on stator covers and found about 8 other nuts slightly loose.

The ISO phase fan & filters were checked:
REMARKS: Replaced fan belts because one in the set was found cracked. Replaced filter with a clean one and cleaned the inside of the fan housing.

Depression air tanks inspected:
REMARKS: Minor scaling of paint. Painted with Agway Zinc Cromate red primer.

Upper wear ring strainer:
REMARKS: Found clean.

Lower wear ring strainer:
REMARKS: Found clean.

Packing box strainers checked and cleaned:
F \RKS: Found 60% plugged.

Clean flow orifices cooling water lines El. 825:
REMARKS: Flushed and cleaned

Clean flow orifices seal water El. 795:
REMARKS: Flushed and cleaned.

Barton flow meters checked and calibrated as Listed on BG O & M 331 DATED: 10-29-81
REMARKS: 80WTSU adjusted slightly.

The 1-2-3-4 Oil coolers WERE CHECKED
REMARKS: Oil coolers 1-2&4 were found with the channel to tube gasket broken and small amounts of grass were found in coolers. Cleaned coolers and replaced gaskets, top and bottom.

Thrust bearing oil cooler water flow was adjusted as shown on BG O & M 346
REMARKS: Not done DATED: XXXXXX

, cooler number 3 was inspected by removing Top & Bottom covers
F ARKS: New gaskets installed. Back of cooler covered with about 5% paper debris a tar like substance found on stator ledges. Cleaned ledges behind No.3 cooler.

ANNUAL MAINTENANCE

UNIT # 2

DATE: 11-3-81

o ing water pump # XXXXX was checked:
F RKS: Not Checked.

rake ring nuts were checked for tightness:
EMARKS: One found loose. Re-welded.

rake wear readings were taken and are shown on BG O & M 314 DATED: 10-16-81
EMARKS: Wear since new Jan. 1975. 2.43MM

he rotor was checked for breakaway and the high pressure oil pump life was hecked this is shown on BG O & M 326 DATED: 10-13-81
EMARKS: Breakaway, -125 from last time checked, lift the same as last year.

he jacking pump was checked by lifting the unit:
EMARKS: 3100 Lbs. to jack uint, pump worked good. Gauge out of calibration.

he deflection meter was adjusted to 0 with no weight on the bearing springs:
EMARKS: 15 Mils with weight on unit, last time meter would not zero and with weight on unit it read 7 Mils.

isual inspection of the thrust runner and thrust bearing shoes were made:
EMARKS: Found normal.

visual inspection of internal high pressure oil system was checked for leaks and loose bolts and clips:
EMARKS: No defects found.

The high pressure oil system was checked as shown on BG O & M 334 DATED: 10-27-81
REMARKS: All found normal.

Oil filters on the suction and discharge side of the high pressure oil pump were checked:
REMARKS: Both filters were found clean, replaced all o-rings on vents and canasters.

The oil was removed from all bearings:
REMARKS: And refilled with centrifuged oil.

T gap at the air box and shaft above upper guide bearing was checked before a after bearing adjusted and is shown on BG O & M 333 DATED: 10-14-81 & 10-20-81
ARKS: All within normal limits

ANNUAL MAINTENANCE

UNIT # 2

DATE: ____________

.c r guide bearing air box gap was checked before and after bearing adjust-
ıent this gap was as shown on BG O & M 313 DATED: 10-14-81 & XXXXXXXXX
REMARKS: All found normal. Air box found with cracks around vent piping

Before bearing adjustments were made the turbine shaft was checked for plumb.
This is shown on BG O & M 354 DATED: 10-19-81
REMARKS: .0125 top lean North
.004 top lean West

After bearing adjustment plumb was again checked and shown on BG O & M 354
DATED: XXXXXXX
REMARKS: Not checked .

Bearings were checked for proper clearances and this is shown on BG O & M
353 DATED: 10-15-81 BG O & M 351 DATED: 10-15-81 BG O & M 352 DATED: 10-15-81
REMARKS: Bearings are within normal limits. No adjustments needed.

The oil casing gap at the thrust runner was measured before and after bearing
alignment. This is found on BG O & M 336 DATED: 10-14-81 & XXXXXXXXXX
REMARKS: No adjustment needed. Found within normal limits.

The shaft packing box was inspected:
REMARKS: Found to be in normal condition. All 5/8" and 1/2" bolts on packing box
covers replaced with new ones. Packing box was sand blasted and painted.

Packing wear is shown on BG O & M 327 DATED: 10-20-81 O & M 322 DATED: 10-20-81
O & M 322 DATED: XXXXXXXXX
REMARKS: Resin worn 14% since new in 1980.
Carbon worn 15% since new in 1980.

The wear of the shaft sleeve at the carbon and resins packing are shown on
BG O & M 359 DATED: 10-19-81
REMARKS: Wear for one year, top .0003, slight heat checks in this area.
Wear for one year, bottom .001

After changing the packing box packing the packing clearance readings were
taken and are shown on BG O & M 321 DATED: 10-19-81

Clearance readings of the turbine before and after bearing adjustments and
cavitation repairs BG O & M 310 DATED: 10-13-81 & DATED: 10-27-81
REMARKS: All readings normal.

Inspection of top of turbine at inspection holes in head cover:
REMARKS: Found normal, new gasket installed.

BG O & M 362

ANNUAL MAINTENANCE

UNIT # 2

DATE: 11-3-81

n ction of cavitation of turbine below lower wear ring:
EMARKS: This area of cavitation has pretty much stabilized and is not getting too much worse. See sketch "A". (3) bolts missing. Replaced (1) bolt, threads stripped in (2) holes weld openings, welded area about 36" long on north east section, cavitation about 3/8" deep.

he lower wear ring was checked for being attached properly:
EMARKS: Appears to be attached properly.

avitation of turbine was checked and materials used for repair of cavitation s shown on BG O & M 317 DATED: 11-3-81
EMARKS: See BGO&M 317.

avitation of the nosecone was checked:
EMARKS: Cavitation is the same as last year, area of minor cavitation is not getting larger or deeper.

poxy coating of the turbine was checked:
EMARKS: Most epoxy is now gone.

poxy paint was placed on the turbine and placement is shown on BG O & M 315 DATED: XXXXXX
EMARKS: None place.

emperature relays and dial thermometers for upper guide bearing were checked nd calibrated. Results shown on BG O & M 344 DATED: 10-16-81
EMARKS: One dial thermometer needed adjustment.

Thrust and lower guide bearing temperature relays and dial thermometers were checked and calibrated as shown on BG O & M 343 DATED: 10-16-81
REMARKS: Two dial thermometers needed adjustment and RTD's needed recalibration.

Turbine guide bearing and shaft packing box temperature relays and dial thermometers were checked and calibrated. Results shown on BG O & M 355 DATED: 10-15-81
REMARKS: Bearing shut down relay did not operate properly the first time. Test department had problem with recorder. recalibrated recorder.
Packing box shutdown relay not tested.

Generator air cooler dial thermometers were checked and are shown on BG O & M 342 DATED: 10-28-81
REMARKS: Adjusted coolers 1,5 & 6

ANNUAL MAINTENANCE

UNIT # 2

DATE: 11-3-81

)' level annunciators and level gages were checked and shown on BG O & M 3: DATED: 10-23-81
REMARKS: All ok, nothing was reset.

Items in the turbine pit were checked as shown on BG O & M 345 DATED: 10-29-81
REMARKS: See BGO&M 345

The prime pressure switches were checked as shown on BG O & M 345 DATED: 10-29-81
REMARKS: Found ok not adjusted.

Bolts, nuts and hangers in the generator housing were checked:
REMARKS: Very few loose.

Bolts, nuts and hangers in turbine pit were checked:
REMARKS: Grease stem fitting loose, and tightened.

Bolts, nuts, hangers and piping were checked on the sperical valve system:
REMARKS: Several loose clamps found and tightened.

: oll case drain valve bolts were checked for torque:
REMARKS: All found ok.

Runner band drain valve bolts were checked for proper torque:
REMARKS: All found ok.

The draft tube throat liner was checked:
REMARKS: Found in good condition.

The O rings on the scroll case access door was checked:
REMARKS: Replaced with new o-ring.

The gasket on the draft tube access door was checked:
REMARKS: Checked ok, not replaced.

The oil from the governor sump and pressure tank was removed:
REMARKS: Both tank and sump cleaned. new teflon gaskets placed on tank mandoors.

,. complete governor inspection was made and items checked as shown on BG O & M 338 DATED: 10-30-81 BG O & M 339 DATED: 10-30-81 BG O & M 340 DATED: 10-30-81
REMARKS: Replaced cracked pilot valve housing.

BG O & M 364

ANNUAL MAINTENANCE

UNIT # 2

DATE: 11-3-81

icket gate seal inspection defects show on BG O & M 324 DATED: 10-13-81

p. seals replaced: Seven, two were original seals installed with unit.

ower seals replaced: Fourteen, two were original seals installed with unit.

fter seal replacement clearance readings were taken and are shown on BG O & M 12 DATED: 10-14-81

EMARKS ON WICKET GATE SEALS: All within normal height limits.

icket gate stem leakage checked and adjustment to 0 stems was made ue to excessive leakage see BG O & M 341 DATED: 10-30-81

EMARKS: Repacked No.15 and 20 wicket gate stem with Sepco packing.
Replaced bolts in No.3 stem and one bolt in No.1 stem.

pherical valve seal and body measurements were checked on the downstream eal and are shown on BG O & M 329 DATED: 10-13-81 All normal

he upstream seal was checked for leakage:

EMARKS: No leakage at this time.

The downstream seal was checked for leakage:

REMARKS: Leakage of 4400 milliliter minute. See sketch "B" dated 10-28-81.
Leakage of 5454 milliliter minute on supply water to put seal on, leak at) position. This leak was measured at 5181 milliliter minute.

The 10" by pass guard valve was checked for leakage:

REMARKS: No leakage.

The spherical valve oil filter was cleaned:

REMARKS: Found clean.

The couplings on the spherical valve oil pumps were checked:

REMARKS: Inspected and found ok.

The spherical valve pressure switches were checked as shown on BG O & M 131 DATED: XXXX

REMARKS: Not Checked.

Painting was done on the following during this maintenance:

Packing box sand blasted and painted.
Interior bottom section of air depression tanks painted.
Phase reversing switches painted.

ANNUAL MAINTENANCE

UNIT # 2

DATE: 11-3-81

'he wicket gate backlash measurement was taken and is as shown on BG
ı & M 332 DATED: 10-29-81
:EMARKS: Backlash .006 Last time .0055

!icket gate bushing movement readings were taken and are as noted on BG O & M
ı37 DATED 10-22-81 Three copies.
:EMARKS: Bushing movement is increasing on the wicket gate stems. Last year average .0071, this year .0113.

!icket gate head cover and stay ring clearance were taken and are as shown
ın BG O & M 311 DATED 10-28-81
:EMARKS: All readings in normal limits.

'est welding rod was used on bucket # XXXX to attempt to find a substitute
ıelding rod for turbine. This rod was XXXXXX
'he placement of this rod is noted on BG O&M 315 DATED XXXXX
:EMARKS: Not tested this time.

I ,ected operation ring guide strip
:EMARKS: North section removed and checked, found good. Replaced after cleaning.

The following other jobs were performed on this unit.
REMARKS: Repacked No15 and No.20 wicket gate stems with packing made by Sepco Co.

Modified Iso phase dampers, elevation 855

Repaired crack in thrust bearing air box

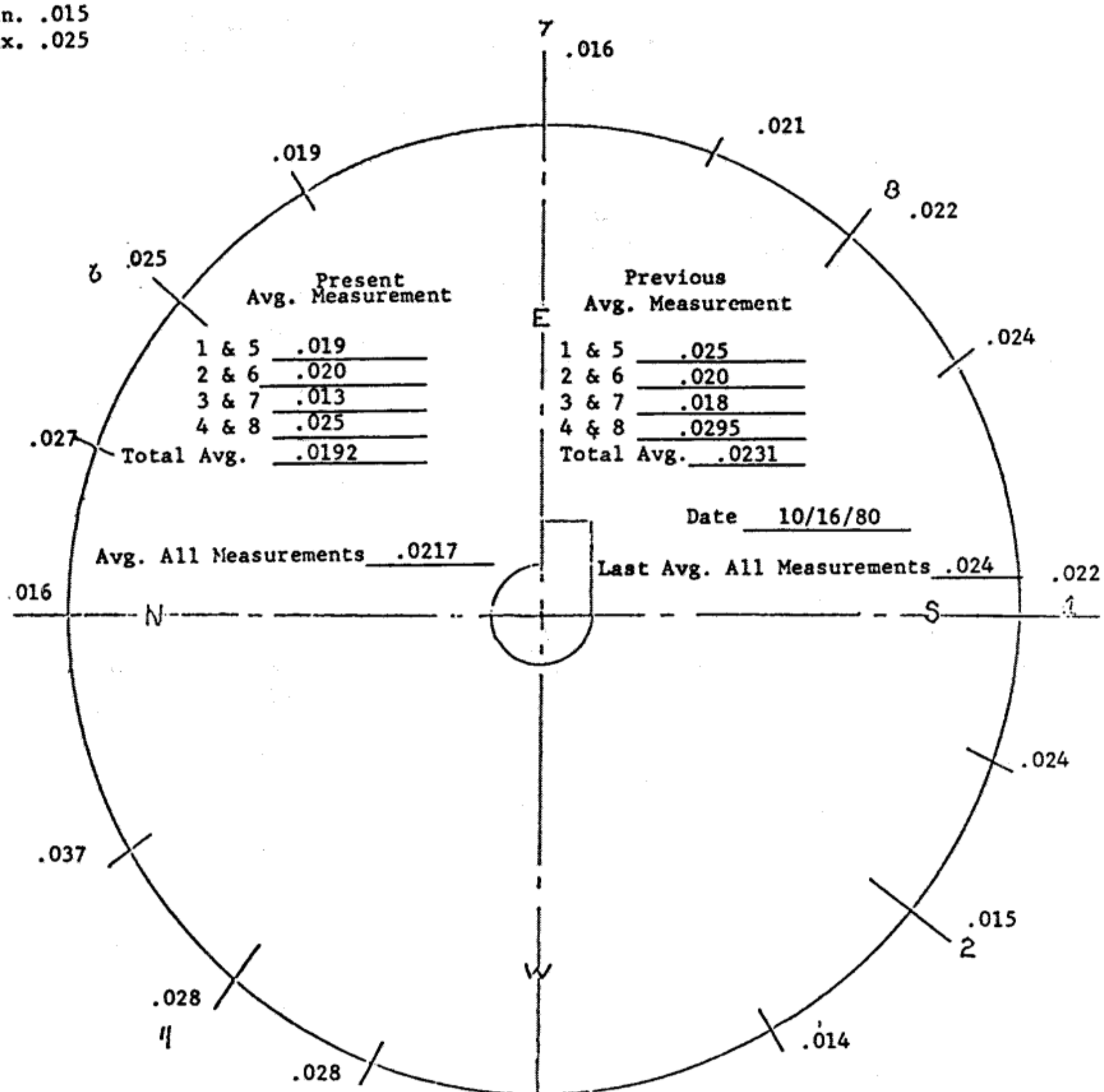
Painted reversing switch

Unit # 2

Oil Sealing Box Gap At Shaft

Thrust Brg.

Min. .015
Max. .025



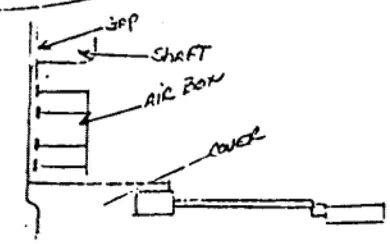
Present Avg. Measurement	
1 & 5	.019
2 & 6	.020
3 & 7	.013
4 & 8	.025
Total Avg.	.0192

Previous Avg. Measurement	
1 & 5	.025
2 & 6	.020
3 & 7	.018
4 & 8	.0295
Total Avg.	.0231

Date 10/16/80

Avg. All Measurements .0217

Last Avg. All Measurements .024



Gen. Hrs. 11317.8
Gen Spin 57.2
Pump Hrs. 13671.7
Pump Spin 61.7

#4

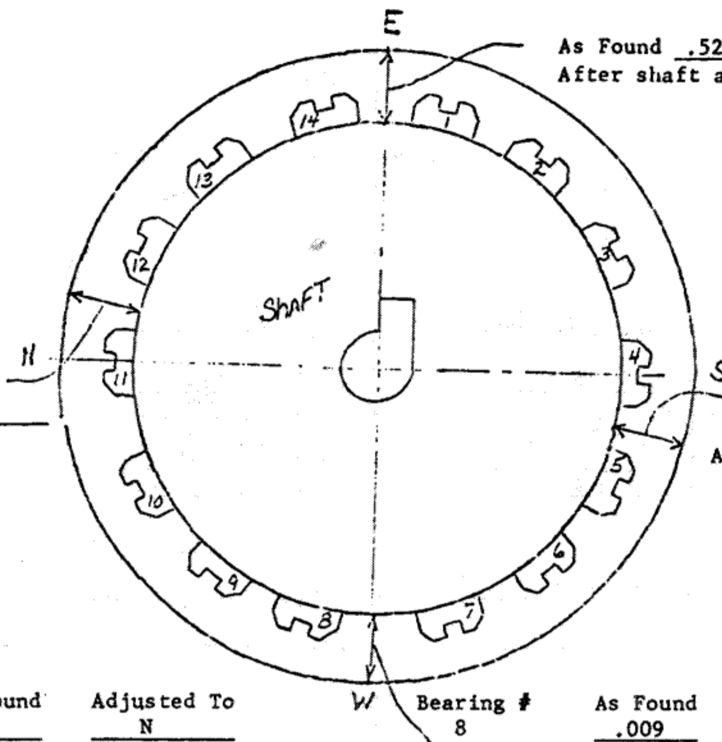
Checked by RV JB RP Date 10-14-8

BG O&M 313

UNIT # 2
Lower Guide Bearing Adjustment

.008 Min.
.011 Max.

As Found .521
After shaft adj. ______



Found .506
ter shaft Adj. ______

As Found .494
After shaft adj. ______

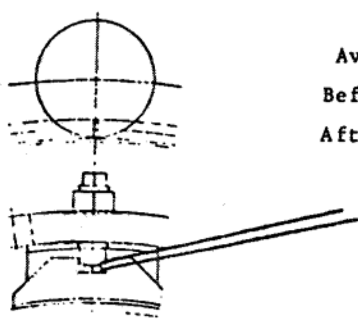
[illegible]ing #	As Found	Adjusted To	Bearing #	As Found	Adjusted To
1	.009	N O	8	.009	N O
2	.006	T A	9	.011	T
3	.002	D J	10	.014	A D
4	.001	U S	11	.016	J U
5	.002	T E	12	.016	S T
6	.003	D	13	.015	E D
7	.005		14	.012	

As Found .4855
After shaft Adj. ______

Avg. distance between shaft to Brg. Housing

Before ______

After ______



Average Bearing Clearance

Before Adjustment .0086

After Adjustment ______

Brg. Gap

Gen Hrs. 11317.8
Gen Spin 57.2
Pump Hrs. 13671.7
Pump Spin 61.7

#5

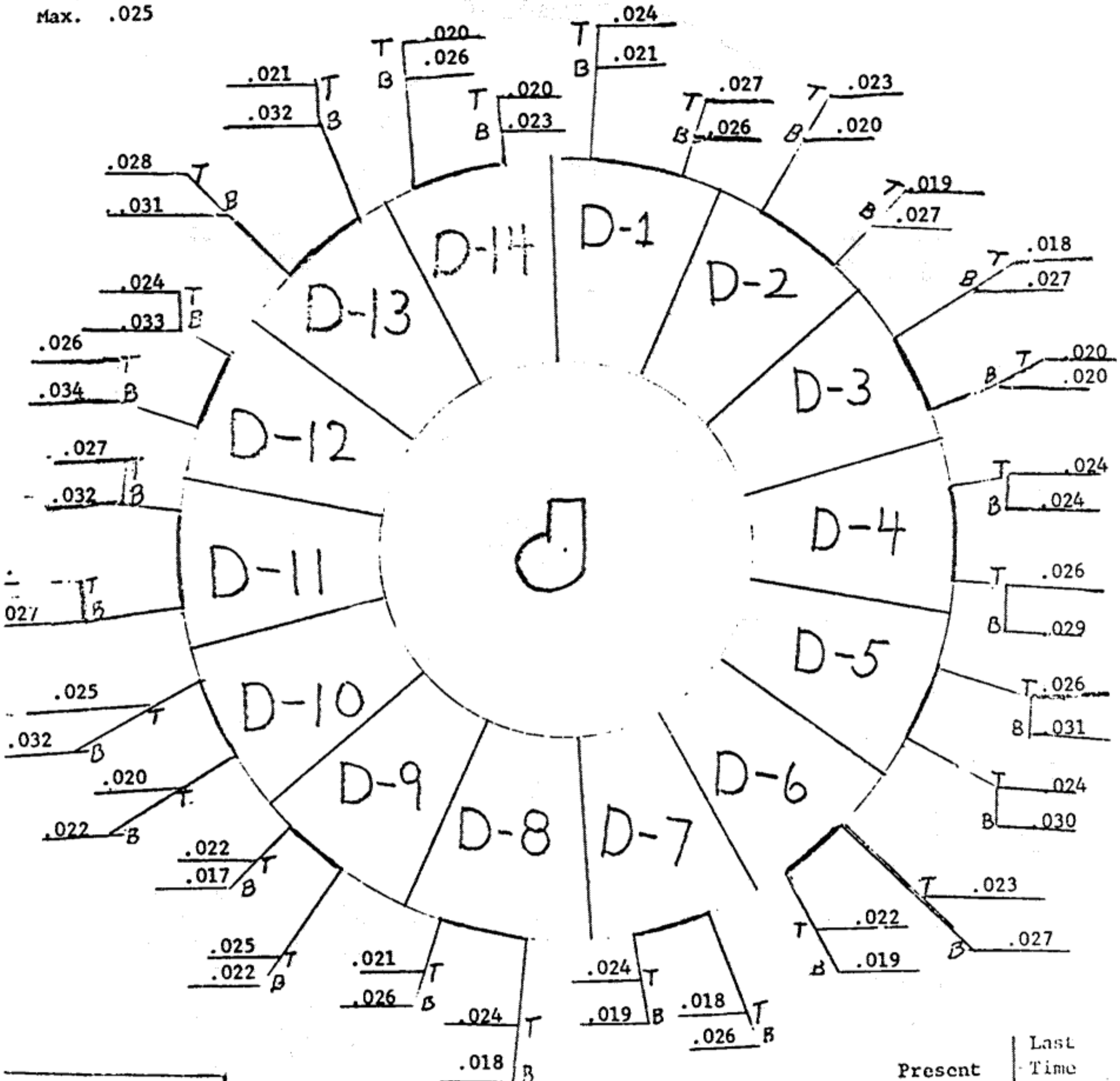
Checked By RV BP RC JB BP Date 10-15-81
BG O&M 353

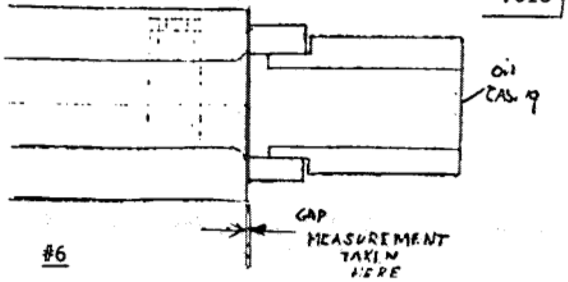
UNIT # 2

BGO&M336

GAP AT THRUST RUNNER VISCOSITY PUMP

Min. .018
Max. .025





Gen. Hrs. 11317.8
Gen Spin 57.2
Pump Hrs. 13671.7
Pump Spin 61.7

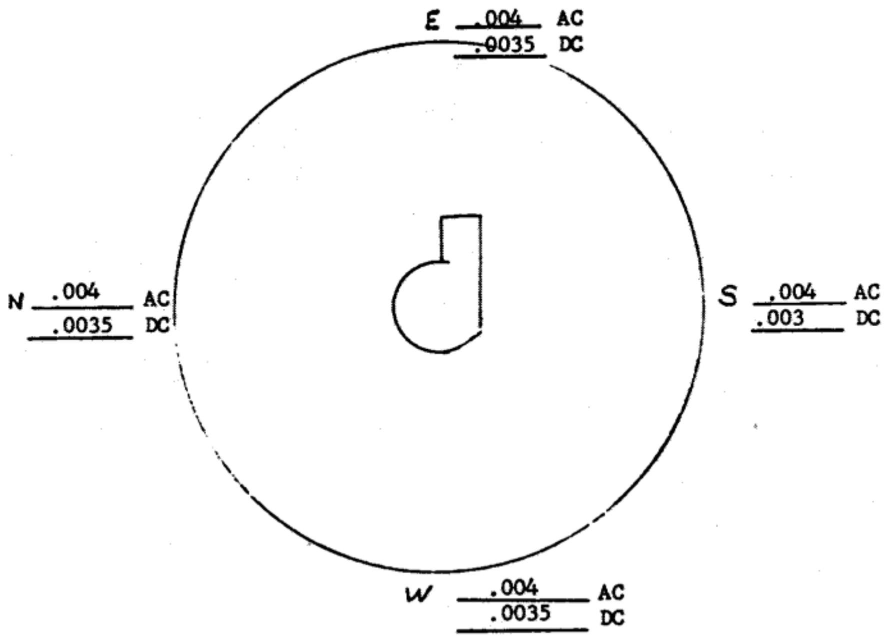
	Present	Last Time
Avg. Top	.023	.0231
Avg. Bottom	.0257	.0244

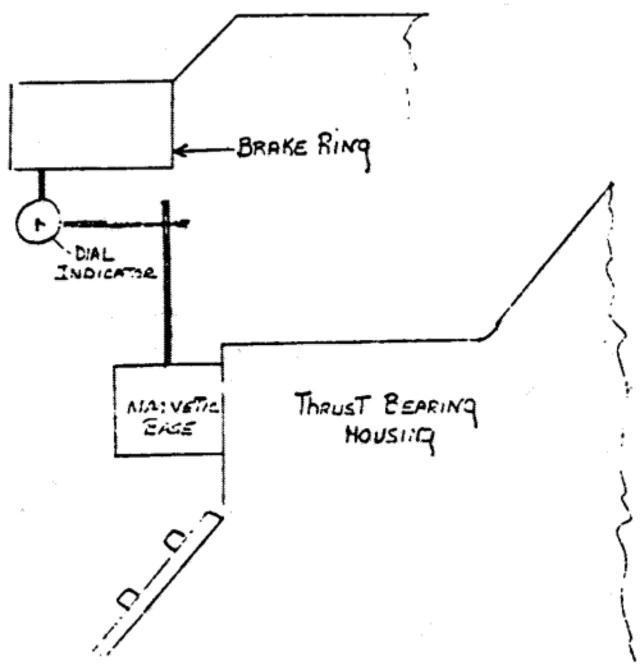
#6

Checked by RV JB RP Date 10-14-81
REVISED BGO&M 336

Unit # 2
Thrust Bearing Lift
AC & DC Hi Pressure oil pumps

BGO&M326





750 Lbs. to Breakaway
w/Dynamometer
-125 Lbs. Change since last time checked

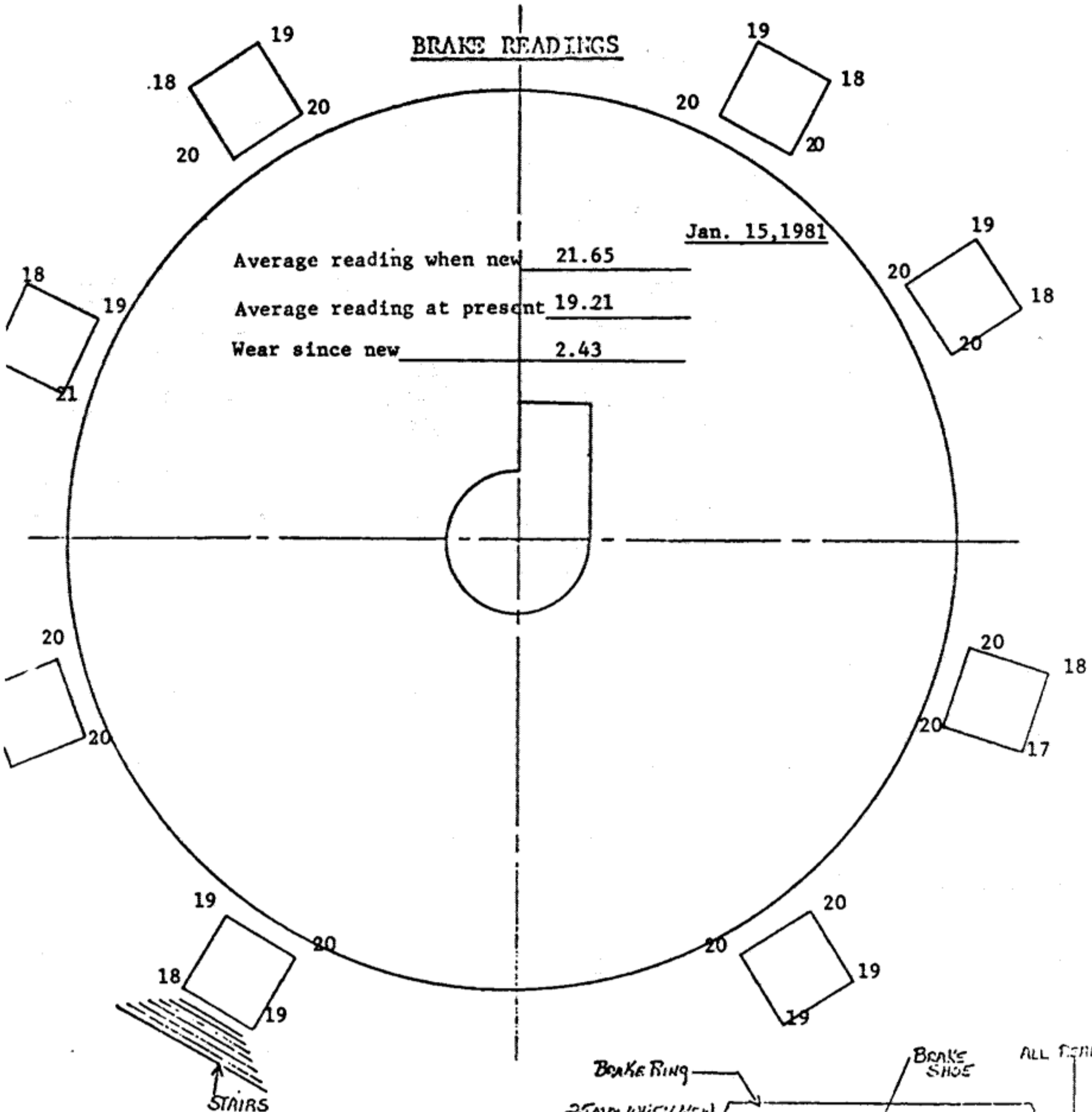
Gen. Hrs. 11317.8
Gen. Spin 57.2
Pump Hrs. 13671.7
Pump Spin 61.7

#8

Checked by WB RP RV Date 10-13-81
BG O&M 326

Unit # 2

BRAKE READINGS



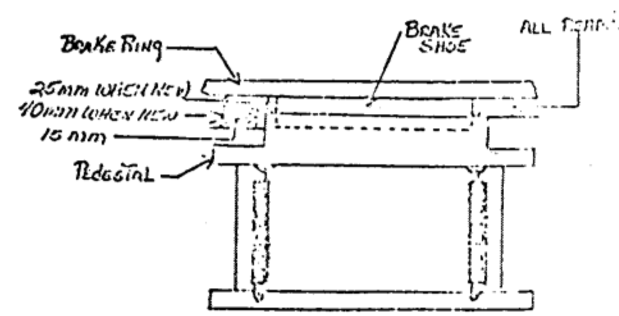
Jan. 15,1981

Average reading when new 21.65

Average reading at present 19.21

Wear since new 2.43

STAIRS



Brakes should be replaced when readings are 10mm, must be replaced when readings are 7mm on any one of the shoes

Gen. Hrs. 11317.8
Gen. Spin 57.2
Pump Hrs. 13671.7
Pump Spin 61.7

Stops 4562
Starts 4562

Checked by WK GS Date 10-16-81
BG O&M 314

#9

Unit # 2
High Pressure Oil System

** Indicates critical setting

Pr ,ure Switch # 24
(C :k Valve Failure)

	On **	Off
Should Be	150	145
As Found	150	70
Set To	150	70

Pressure Gage # 25

Dead weight tested & checked at 1500 lbs.	OK 1500
Dead weight tested & checked at 1600 lbs.	OK 1600
Clean face glass	OK

Pressure Switch # 23
(Unit AC Pump Start)

	On	Off
Should Be	1300	1100
As Found	1302	1055
Set To	1302	1055

AC PUMP PRESS. 1700 PSI

DC PUMP PRESS. 1325 PSI

When test operated from cabinet

Pressure Switch # 22
(Unit DC Pump Start)

	On	Off
Should be	1300	1100
As Found	1290	1040
Set To	1300	

Inspect # 13 Check Valve
Not Checked

I pect # 14 Check Valve
Not Checked

Inspect # 15 Check Valve
Not Checked

Inspect # 16 Check Valve
Not Checked

Inspect Piping
No leaks found

* Time of Pressure reducing in high pressure circuit

Unit Stand Still	1700 - 150	5.9 Sec.	Orifice Setting	11/12
Original	1700 - 150	3.5 Sec.	Original	9/12

Gen Hrs. 11317.8
Gen Spin 57.2
Pump Hrs. 13671.7
Pump Spin 61.7

*Should be less than 20 sec. but could vary by oil temperature

Checked By RV WB Date 10-27-81
BG O&M 334

#10

UNIT # 2

GENERATOR AIR COOLER
DIAL THERMOMETER READINGS

DIAL THERMOMETERS

Air Cooler #1 (31to26)

Dial Indicator	31	26	50°	ANN. ✓
Oil Bath Temp.			53	✓
Ambient Temp.	26	26		

Air Cooler #2

Dial Indicator		26	50°	ANN. ✓
Oil Bath Temp.			52.3	✓
Ambient Temp.		26		

Air Cooler #3

Dial Indicator		26	50°	ANN. ✓
Oil Bath Temp.			51.7	✓
Ambient Temp.		26		

r Cooler #4

Dial Indicator		26	50°	Ann. ✓
Oil Bath Temp.			51.3	✓
Ambient Temp.		26		

Air Cooler #5 (22to26)

Dial Indicator	22	26	50°	Ann. ✓
Oil Bath Temp.			51.5	✓
Ambient Temp.	26	26		

Air Cooler #6 (24to26)

Dial Indicator	24	26	50°	Ann. ✓
Oil Bath Temp.			55	✓
Ambient Temp.	26	26		

Air Cooler #7

Dial Indicator	26		50°	ANN. ✓
Oil Bath Temp.			55	✓
Ambient Temp.	26			

Air Cooler #8

Dial Indicator	26		50°	ANN. ✓
Oil Bath Temp.			54	✓
Ambient Temp.	26			

* Remarks Adjusted needles on #'s 1-5-6

Gen. Hrs. 11317.8

Gen. Spin 57.2

PUMP Hrs. 13671.7

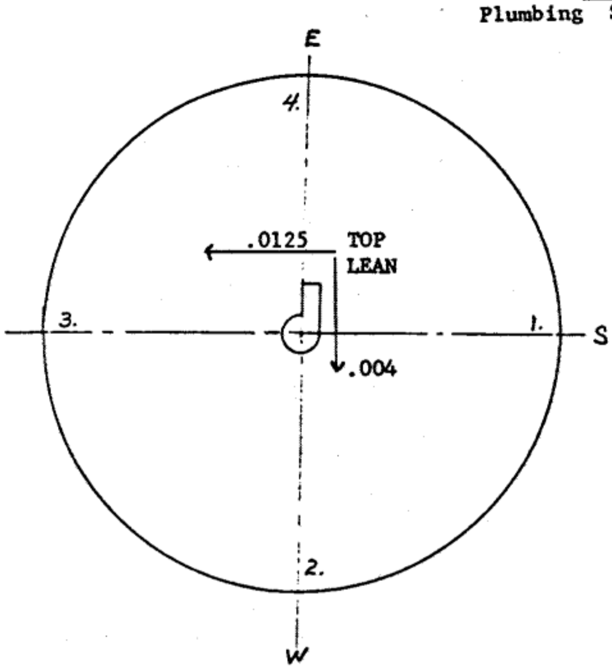
PUMP Spin 61.7

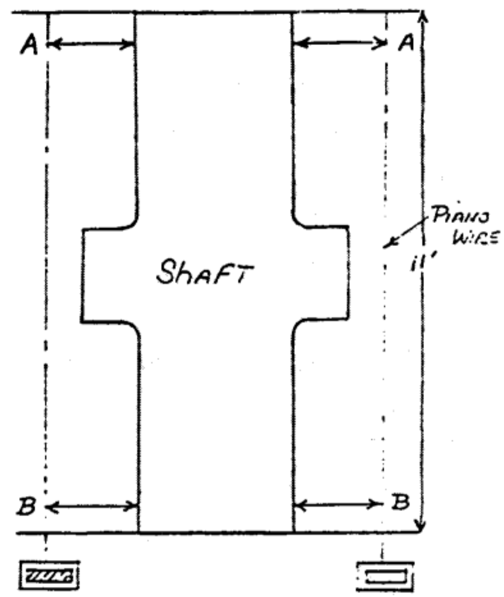
#11

Checked By RV Dug. Date 10-28-81

BGOM-342

Unit # 2
Plumbing Shaft





Step 1

1 397 A3 166

1 407 B3 201

Step 2
Total
A1 & A3
B1 & B3
563
608

Step 3
Shaft Size
Differential
A & B
45

Step 4
½ of Shaft
Size Diff.
22.5

Step 5
Add to Smaller
A1 or ~~B1~~ Rdg
for corrected Rdg.
419.5

Step 6
dd to Smaller
3 or ~~B3~~ Rdg.
or corrected Rdg
188.5

Step 7
Corrected A1 or ~~B1~~ 419.5
Uncorrected ~~A1~~ or B1 407
Out of Plumb .0125

Step 8
Corrected A3 or ~~B3~~ 188.5
Uncorrected ~~A3~~ or B3 201
Out of Plumb .0125

Step 1

.2 273 A4 99

32 284 B4 102

Step 2
Total
A2 & A4
B2 & B4
372
386

Step 3
Shaft Size
Differential
A & B
14

Step 4
½ of Shaft
Size Diff.
7

Step 5
Add to Smaller
A2 or ~~B2~~ Rdg.
for corrected Rdg.
280

Step 6
Add to Smaller
A4 or ~~B4~~ Rdg.
for corrected Rdg.
106

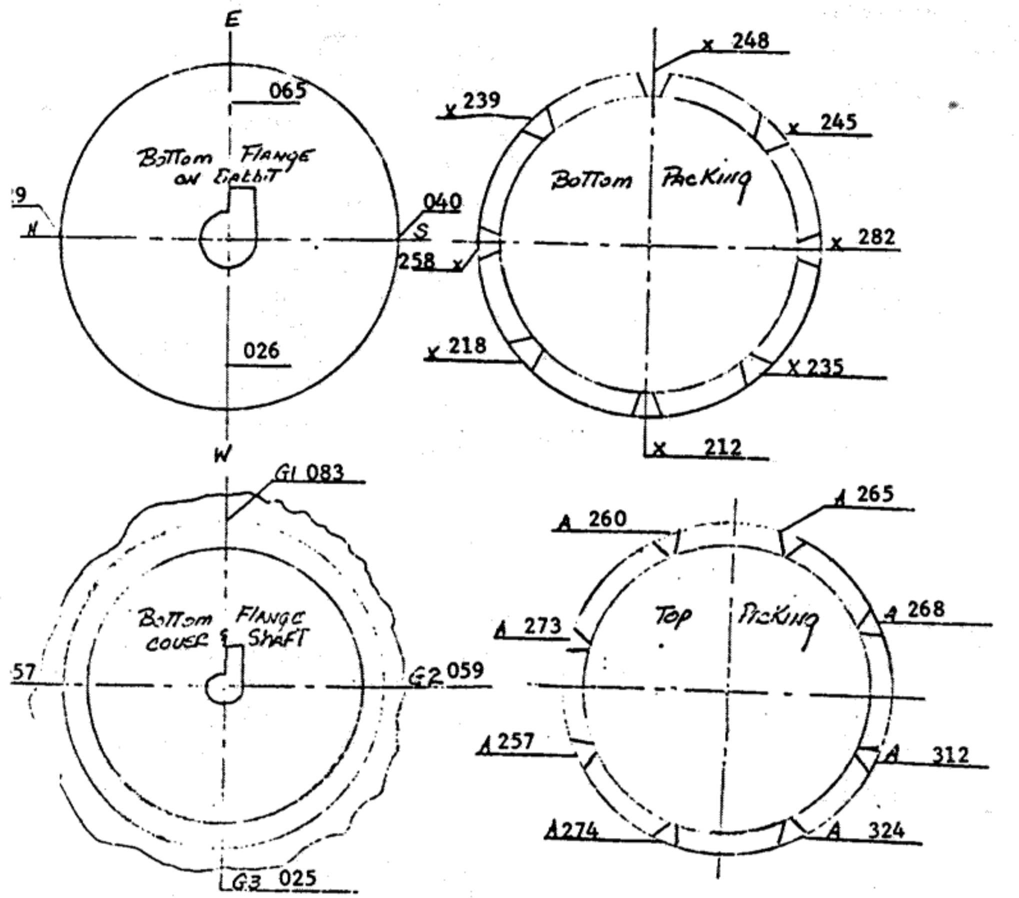
Step 7
Corrected A2 or ~~B2~~ 280
Uncorrected ~~A2~~ or B2 284
Out of Plumb .004

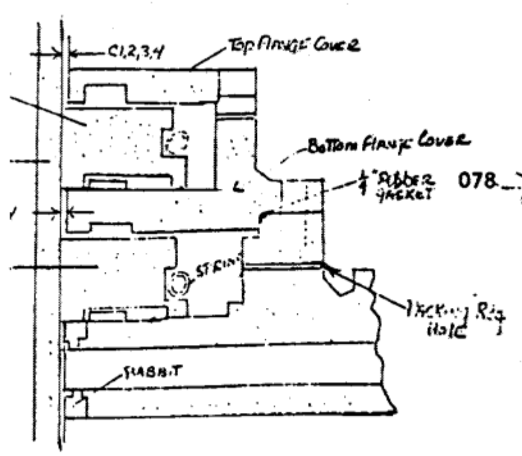
Step 8
Corrected A4 or ~~B4~~ 106
Uncorrected ~~A4~~ or B4 102
Out of Plumb .004

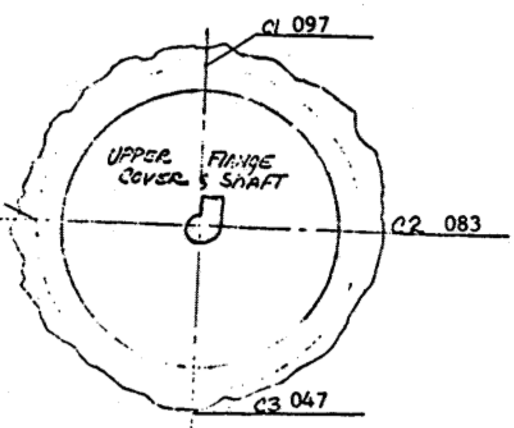
Gen. Hrs. 11317.8
Gen. Spin 57.2
Pump Hrs. 13671.7
Pump Spin 61.7
#12

Checked by GS AJ BK Date 10-19-81
BG O&M 354

Unit # 2
Before/After Changing the Packing (new packing)







Allowable clearances A&X .203 min.
.390 max.

Gen Hrs 11317.8
Gen Spin 57.2
Pump Hrs 13671.7
Pump Spin 61.7
#18

G 1,2,3,4,
C 1,2,3,4, .046 ± .078

Checked by BK JB GS Date 10-19-81
BG O&M 321

UNIT # 2
SHAFT PACKING READINGS

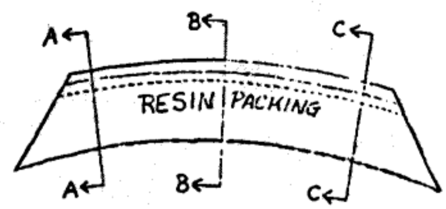
*H Reading - When new packings should be 3.056

PACKING MUST BE CHANGED WHEN WEAR REACHES .750

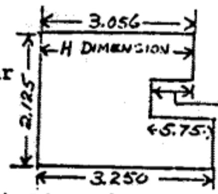
RESIN PACKING (H) dimension

- 1.A 2.939 B 2.932 C 2.950
- 2.A 2.960 B 2.965 C 2.982
- 3.A 2.935 B 2.925 C 2.935
- 4.A 2.933 B 2.934 C 2.938
- 5.A 2.943 B 2.940 C 2.954
- 6.A 2.937 B 2.922 C 2.937
- 7.A 2.963 B 2.952 C 2.965
- 8.A 2.950 B 2.935 C 2.954

A 2.945 B 2.938 C 2.951



Percent of Wear
14%



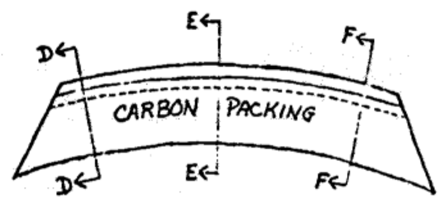
Typical Section

Average Depth 2.944 (H) Dimension

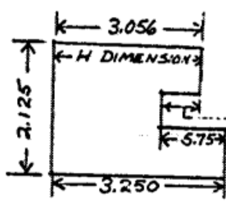
CARBON PACKING (H) dimension

3 - 1.D 2.925 E 2.935 F 2.957
l 2.D 2.930 E 2.935 F 2.960
2 - 3.D 2.932 E 2.945 F 2.971
3 - 4.D 2.937 E 2.941 F 2.957
4 - 5.D 2.917 E 2.931 F 2.955
5 - 6.D 2.922 E 2.943 F 2.970
6 - 7.D 2.927 E 2.941 F 2.972
7 - 8.D 2.925 E 2.936 F 2.953

D 2.926 E 2.938 F 2.961



Percent of Wear
15%



Typical Section

Average Depth 2.942 (H) Dimension

Total Machine Hrs.
Gen Hrs. 11317.8
Gen Spin 57.2
Pump Hrs. 13671.7
Pump Spin 61.7

Dates Packings Changed

Resin	Carbon
10-8-80	10-8-80

Total Run Since Packing Changed

Resin		Carbon	
Gen Hrs.	1796.9	Gen Hrs.	1796.9
Gen Spin	29.2	Gen Spin	29.2
Pump Hrs.	2199.9	Pump Hrs.	2199.9
Pump Spin	14.8	Pump Spin	14.8

Unit # 2

#19

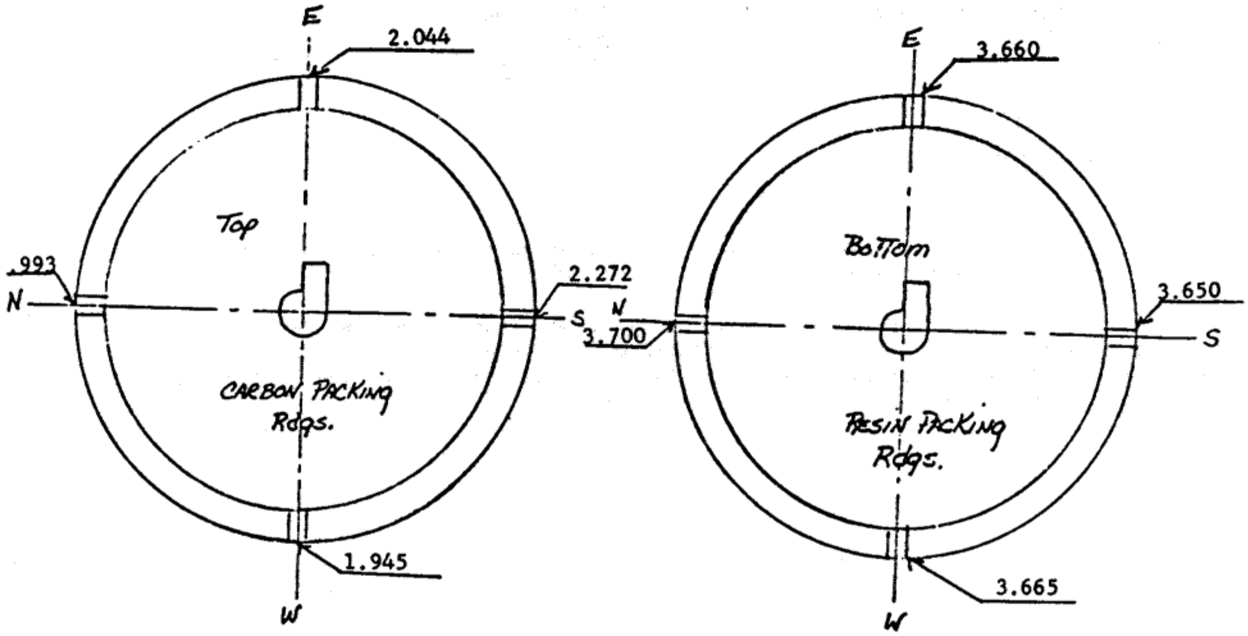
Checked By WP Date 10-20-81

RC OSM 322

Note: Packing must be changed when wear reaches .750

UNIT # 2
PACKING WEAR READINGS
(New)

Packing Box Springs
163" long



			Average
Top - Carbon Average Rdgs	E&W	1.9945	2.0635
	N&S	2.1325	
Bottom - Resin Average Rdgs.	E&W	3.6625	3.6687
	N&S	3.675	
Carbon New Average	E&W	1.898	1.889
	N&S	1.880	
Resin New Average	E&W	3.508	3.511
	N&S	3.515	
Amount of Wear - Carbon	E&W	.0965	.1745
	N&S	.252	
Amount of Wear - Resin	E&W	.1545	.157
	N&S	.160	

23% % Carbon Wear
21% % Resin Wear

Dates Packings Changed

Resin	Carbon
10-8-80	10-8-80

Hrs 11317.8
Spin 57.2
› Hrs. 13671.7
› Spin 61.7

Total Run Since Packing Changed

Resin		Carbon	
Gen Hrs.	1796.9	Gen Hrs.	1796.9
Gen Spin	29.2	Gen Spin	29.2
Pump Hrs.	2199.9	Pump Hrs.	2199.9
Pump Spin	14.8	Pump Spin	14.8

#20

Checked by JB BK WP Date 10-20-81

BG O&M 327

Unit # 2
Wicket Gate Backlash Measurement

Wicket Gate Arm Reading
Open .000
Close .006

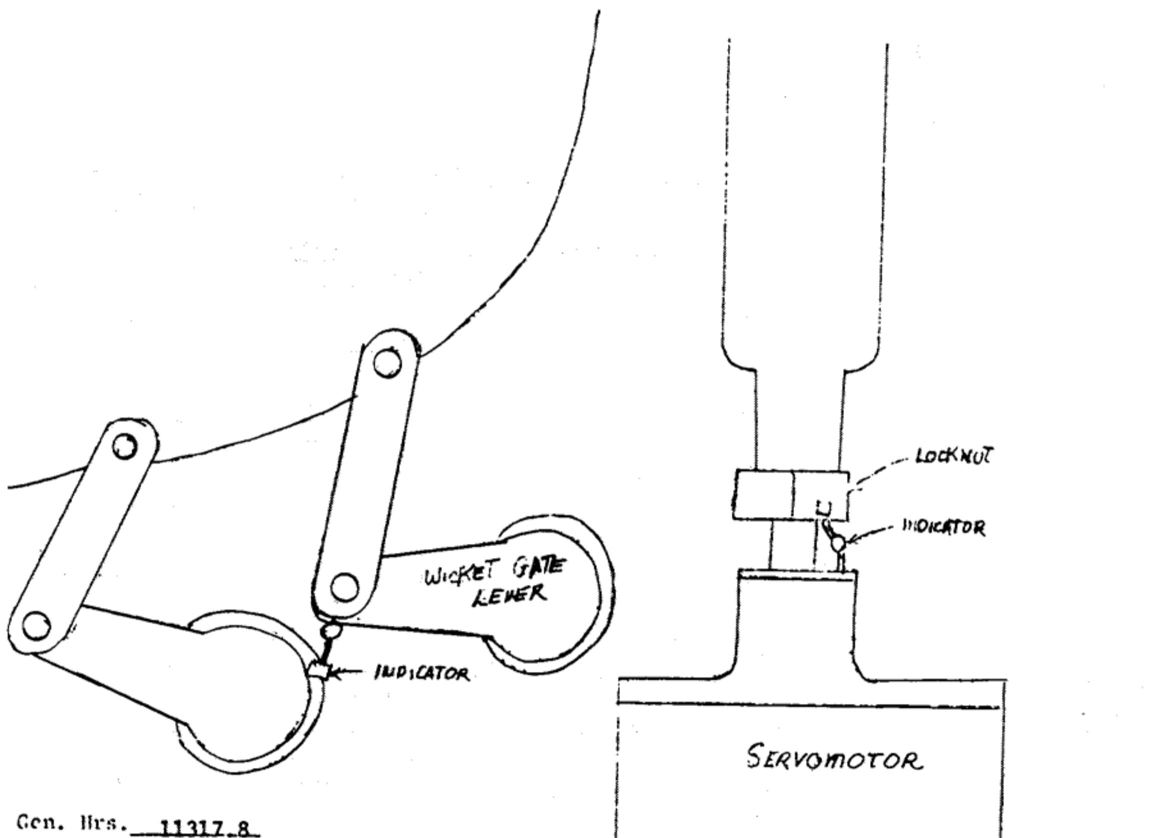
Servo Reading
Open 0
Close 0

Backlash .006

Last time .0055

Open servo any amount greater then backlash (approximately .100) & set indicators on servo & wicket gate arm to .000.

Open servo .100 more & read indicator on wicket gate arm, then close servo same amount (.100) & read indicator on wicket gate arm. Subtract difference between opening & closing, reading on indicator at wicket gate arm to determine amount of backlash



Gen. Hrs. 11317.8
Gen. Spin 57.2
Pump Hrs. 13671.7
Pump Spin 61.7

#22

Checked by RV DW Dug. Date 10-29-81
BG O&M 332

Unit # 2
Wicket Gate Packing Leakage Readings

Tools Needed: 15/16 Socket with 10" extension & 15/16 Open End Wrench
(2) 3/4" Tubing Wrenches

Note: Check grease connections

SL - Indicates slight leak
HL - Indicates heavy leak

Wicket Gate Numbers

1
X SL
Replace
broken bolt

2
SL

3
X X
Replace
bolts
X ok X
X X

4
OK

5
SL

6
OK

7
OK

8
OK

9
OK

10
SL

11
OK

12
OK

13
OK

14
OK

15
Replaced
Packing
10/81 ok

16
OK

17
SL

18
OK

19
OK

20
Replaced
Packing
10-81 ok

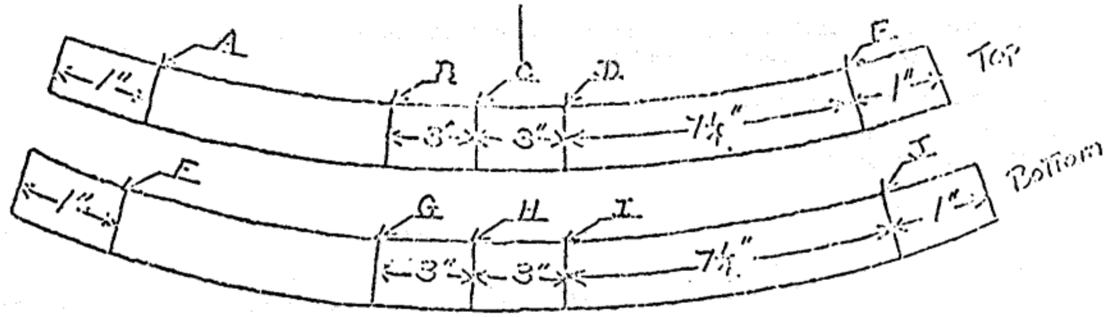
Gen Hrs. 11317.8
Gen Spin 57.2
Pump Hrs. 13671.7
Pump Spin 61.7

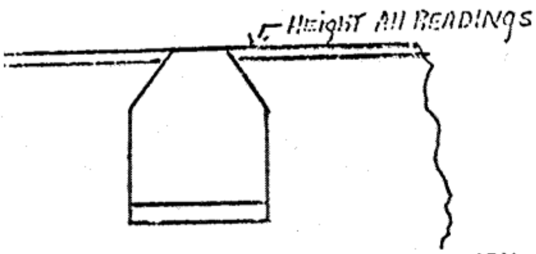
#23

Checked By BK GS . Date 10-81
BG O&M 341

UNIT # 2

WICKET GATE RUBBER SEALS





WHEN REPLACING SEALS, REMOVE SHEAR PIN ON NEXT HIGHTEST No. PIN. EXAMPLE No. 1 SEAL BAD, REMOVE No. 2 SHEAR PIN AND OPEN GATE TO OPERATING RING.

No. 1 SEAL IS THE FIRST SEAL ENTERING SCROLL CASE.

ALL SEALS REPLACED WITH SEALS RECONDITIONED BY MECHANICAL RUBBER CO. Sepco.

BOTTOM READING F	G	H	I	J	SEAL LETTER	TOP READING	B	C	D	E	SEAL LETTER
						1A					
050	045	043	042	045	AX	2A 055	058	060	059	062	CL
052	054	055	052	052	CP	3A 055	058	053	059	059	DQ
						4A					
52	055	055	058	048	CC	5A					
058	058	060	060	058	CJ	6A					
						7A					
						8A					
053	052	054	052	053	CI	9A					
045	047	040	045	056	DM	10A					
						11A 058	053	055	054	058	CS
059	062	058	056	058	CQ	12A					
						13A 057	055	054	055	059	DO
055	055	047	052	065	DK	14A					
056	043	043	045	059	DA	15A 050	054	056	054	051	BQ
052	050	040	035	052	BO	16A					
054	061	050	057	061	CA	17A 051	048	050	047	058	DD
065	060	056	059	056	DM	18A					
060	048	048	053	055	BX	19A					
048	048	061	055	052	DC	20A 060	064	065	062	060	BV

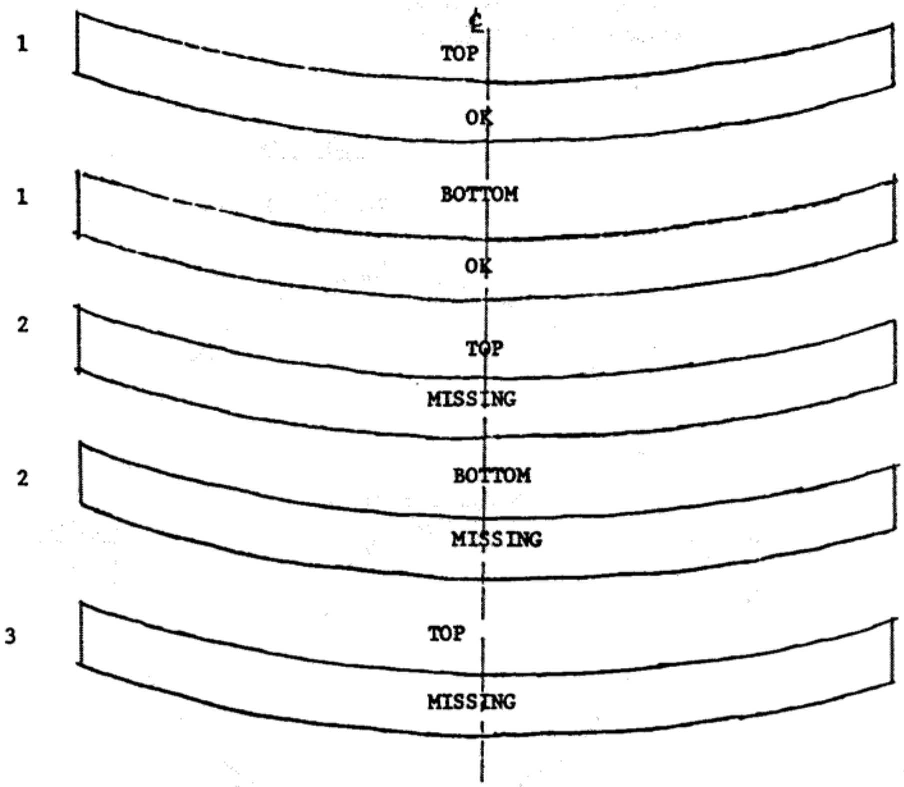
GEN. HRS. 11317.8 GEN. SPIN 13671.7 CHECKED BY GS WP BK

PUMP HRS. 57.2 PUMP SPIN 61.7 DATE 10-14-81

BGOSM 312
REV. #1

#25

Unit # 2
Wicket Gate Seal Cavitation



Gate #	Top	Date Replaced	Bottom	Date Replaced
1	OK	10-20-81	OK	10-20-80
2	Miss	8-9-79	Miss	8-9-79
3	Miss	11-12-73	Miss	10-20-80
4	OK	10-8-76	OK	10-20-80
5	OK	10-8-76	Miss	10-20-80
6	OK	10-8-76	Miss	10-20-80
7	OK	Original	OK	10-20-80
8	OK	8-30-78	OK	10-20-80
9	OK	10-20-80	Miss	Original
10	OK	8-9-79	Miss	10-20-80
11	Miss	Original	OK	10-20-80
12	OK	10-20-80	Miss	10-20-80
13	Miss	10-4-77	OK	11-12-73
14	OK	10-20-80	Miss	10-20-80
15	Miss	8-9-79	Miss	10-20-80
16	OK	8-9-79	Miss	10-20-80
17	Miss	Original	Miss	Original
18	OK	10-20-80	Miss	10-20-80
19	Ok	8-30-78	Miss	10-20-80
20	Miss	3-13-74	Miss	10-20-80

Gen. Hrs. 11317.8
Gen Spin 57.2
Pump Hrs. 13671.7
Pump Spin 61.7

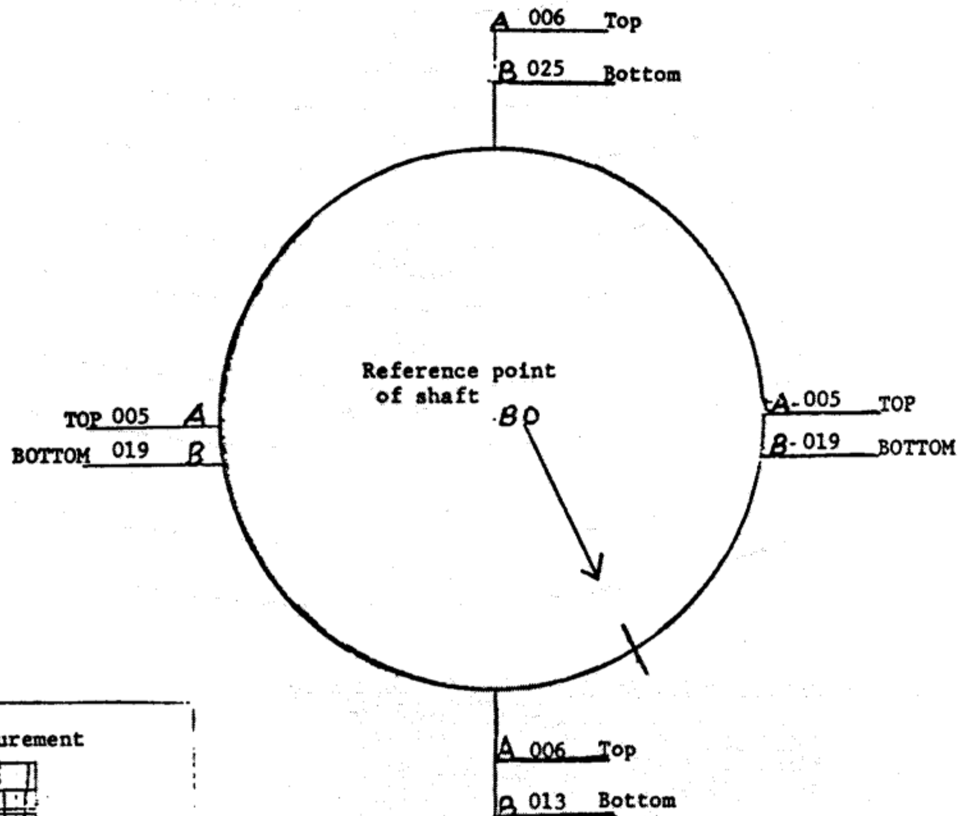
Unit # 2

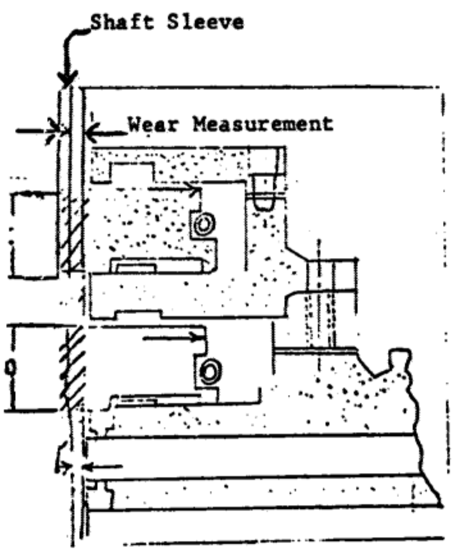
#26

Checked By WP JB BK Date 10-13-81
BG O&M 324

UNIT # 2

Wear of Shaft Sleeve at Carbon & Resin Packing





Average Wear Top .0055

Average Wear Bottom .019

LAST TIME TOP .0052

LAST TIME BOTTOM .018

Gen Hrs 11317.8
Gen Spin 57.2
Pump Hrs 13671.7
Pump Spin 61.7

#21

Checked By GS BK Date 10-19-81
BGO&M 359

Unit # 2

Turbine Clearance Rdgs.

BGO&M 310

BEFORE CAVITATION REPAIR

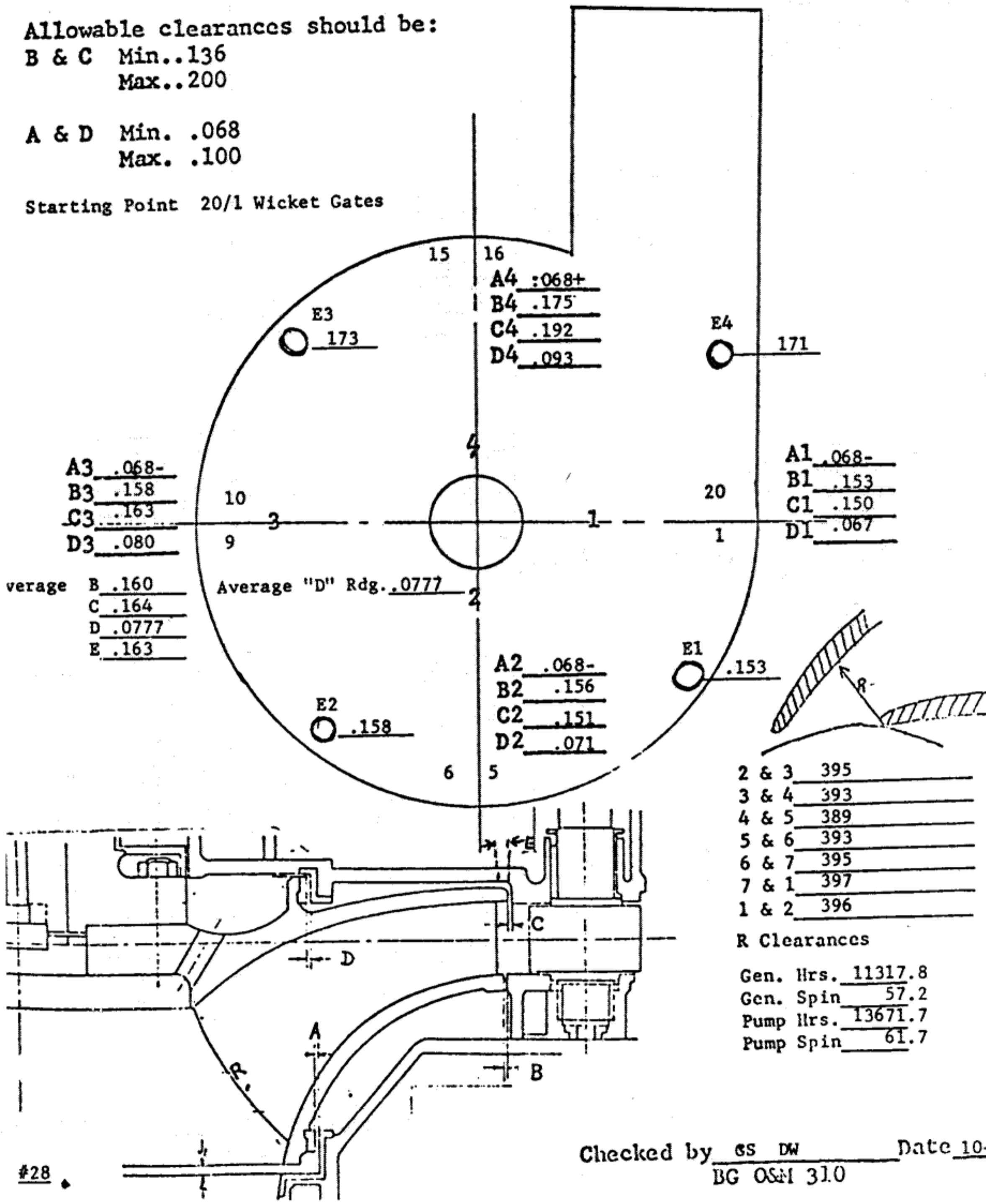
When shaft is center &
.008 clearance on bearing shoes on Turbine
:de bearing

Allowable clearances should be:

B & C Min..136
Max..200

A & D Min. .068
Max. .100

Starting Point 20/1 Wicket Gates



2 & 3	395
3 & 4	393
4 & 5	389
5 & 6	393
6 & 7	395
7 & 1	397
1 & 2	396

R Clearances

Gen. Hrs. 11317.8
Gen. Spin 57.2
Pump Hrs. 13671.7
Pump Spin 61.7

#28

Checked by GS DW Date 10-13-8
BG O&M 310

AFTER CAVITATION REPAIR

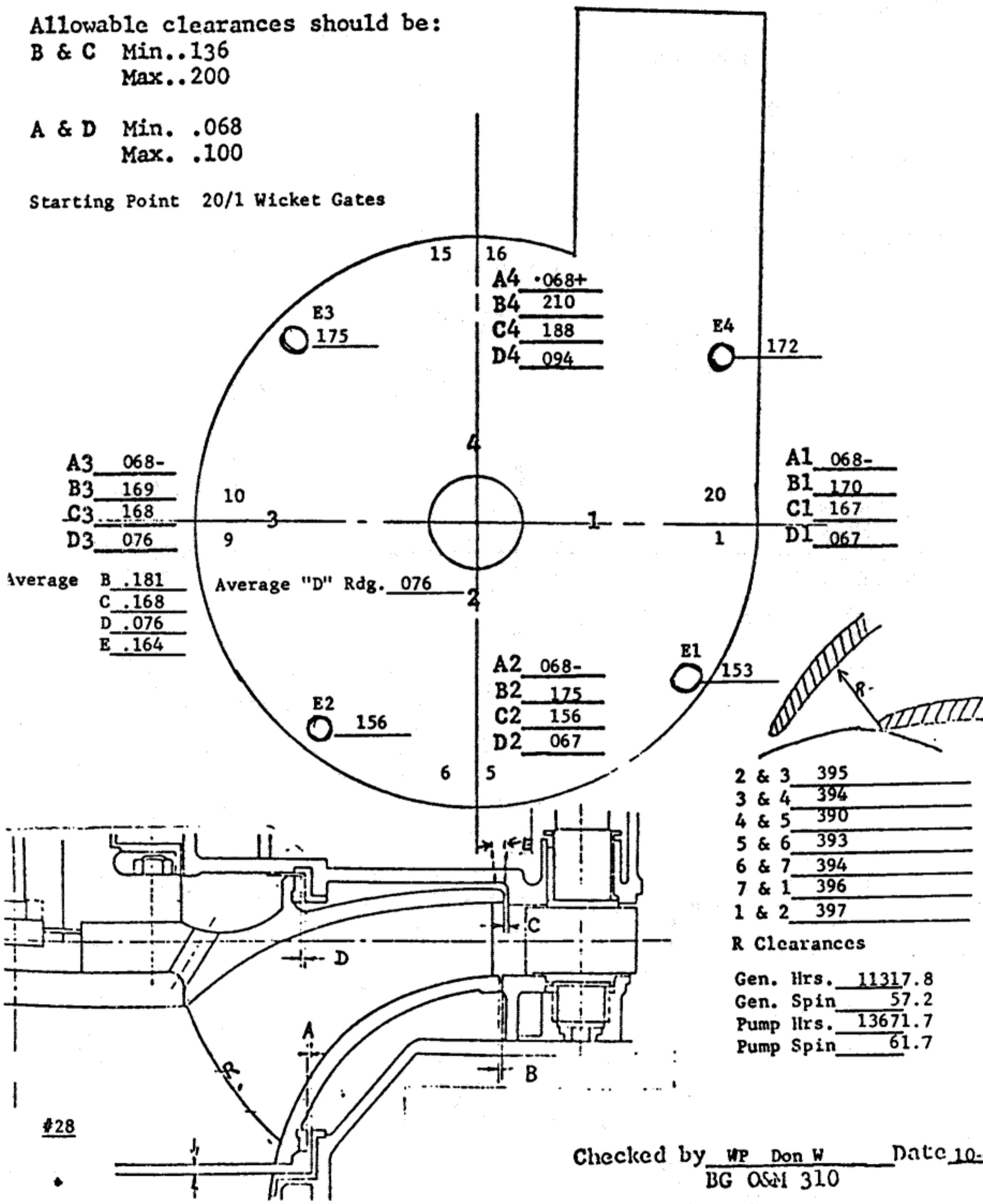
When shaft is center &
.008 clearance on bearing shoes on Turbine
ide bearing

Allowable clearances should be:

B & C Min..136
Max..200

A & D Min. .068
Max. .100

Starting Point 20/1 Wicket Gates



2 & 3	395
3 & 4	394
4 & 5	390
5 & 6	393
6 & 7	394
7 & 1	396
1 & 2	397

R Clearances

Gen. Hrs. 11317.8
Gen. Spin 57.2
Pump Hrs. 13671.7
Pump Spin 61.7

Checked by WP Don W Date 10-27-81
BG O&M 310

Unit # 2
Cavitation Repair Materials & Hrs.

Man Hrs. None Arc Gouging

Man Hrs. 62-1/2 Welding

Man Hrs. 72 Grinding

Carbon Rod Used

Type	Size	Boxes	Number per Box	Total Used
Total Rods				

Welding Rod Used

Type	Size	Cans	Weight of Cans	Total Lbs.
301 Stainless	5/32	5	11 lbs.	55
Total Lbs.				55

Weight of Scrap Welding Rod 14

Actual Quantity of Welding Rod Used in Cavitation 41 lbs.

Grinding Wheels Used

Type		Quantity
Norton 6/4-3/4X 2 X 5/8-11	Cup	2
National Quik Mount 7 X 1/4		15
Blue Hats 4 X 3/16		10
Total Wheels Used		

Sanding Discs Used

Type	Grit	Quantity
Norton	24	99
Norton	50	13
Aloxite	100	17
Total Discs Used		129

Cavitation Work in Progress
From 10-15-81 To 10-21-81

Unit # 2

Checked by HG JL Date 11-3-81
BC O&M 317

UNIT # 2
UPPER GUIDE BEARING
SHUT DOWN RELAYS, DIAL THERMOMETERS, R.T.D.'s

SHUT DOWN RELAYS

Upper Guide Brg. UT-1

Required Trip 105°c
~~100°~~ 1st. try
Oil Bath Temp. 106° 2nd. try

Annunciation ✓

DIAL THERMOMETERS

Upper Guide Brg. Reservoir

Dial Indicator 53 53 55° ANN.

Oil Bath Temp. 50 53 56 ✓

Upper Guide Brg. Shoe# 3

Dial Indicator ____ 55 65° ANN.

Oil Bath Temp. ____ 55.2 64.6 ✓

Upper Guide Brg. Cooling Water Temp.

Dial Indicator ____ 26 40°c ANN.

Oil Bath Temp. ____ 26 42.6 ✓

R.T.D.'s

Upper Guide Brg. Pt.# 1 Shoe# 4

Recorder Temp. 65 68 70°c Ann.

Oil Temp. 65 68 70 ✓

Upper Guide Brg. Computer Shoe# 8

Computer Temp. ____ 60.2 OK ANN.

Oil Bath Temp. ____ 59.8 OK ____

Upper Guide Brg. Oil Res. Computer

Computer Temp. 59 62 ____ ANN.

Oil Bath Temp. 60 62.8 ____ ____

Upper Guide Brg. Oil Res. Pt. # 6

Recorder Temp. ____ 66.5 70°c ANN.

Oil Bath Temp. ____ 65 68.5 ✓

* Remarks Adjusted needle

(25108.5)
Gen. Hrs. 11317.8

Gen. Spin 57.2

Pump Hrs. 13671.7

Pump Spin 61.7

Checked By WP GW Date 10-16-81

BGOM 344

UNIT # 2
Annual Maintenace of Turbine

Test Prime Pressure Switch

	# 1		# 2
Should Be	425	Should Be	403
As Found	425	As Found	404
Set To	425	Set To	404

Main Shaft Leakage Heavy leadage east side Packing not run in.

Wicket Gate stem leakage See BG O&M 341

Condition of Wicket Gate Pins, Arms, & Linkage Ok

Condition of all grease lines Ok

Condition of all pipes & flanges Ok. Replace 6" clamp for pipe north east side.

Condition of Operating Ring Removed north side ok.

Condition of Wicket Gate Servo & Pins Ok.

Condition of Turbine Guide Bearing Ok.

Condition of Bearing Journal Ok.

Condition of Scroll Case Good

Condition of Wicket Gates Ok

Bearing oil tested Not tested

Condition of Packing Box Strainers 60% plugged.

Condition of Upper & Lower Wear Ring Strainers Found clean

Other items inspected & worked on at this time Dismantled packing box, removed north side of operating ring Stoned ok.

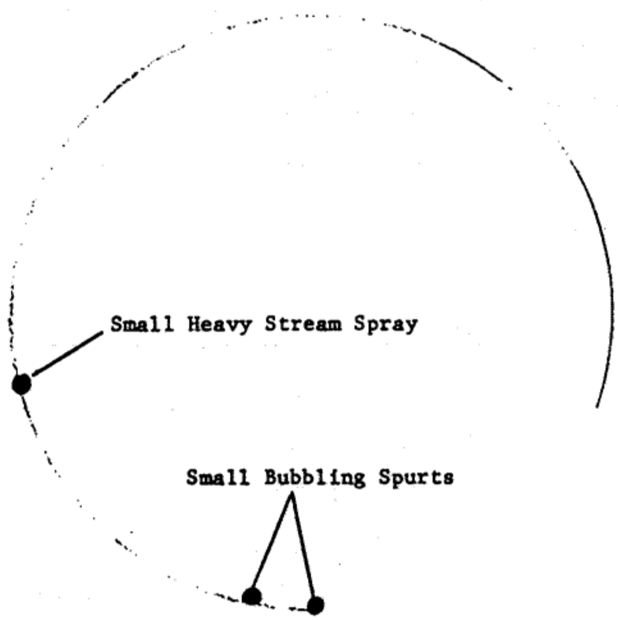
#29

Checked by GS Date 10-29-81

BG O&M 345

DOWNSTREAM
SEAL LEAKAGE
UNIT # 2

* NOTE LS=Light Spray
HS=Heavy Spray
B= Bubble



Total Leakage

4400 Milliliter Min.

Last Time Total

1080 Milliliter Min.

Sketch B

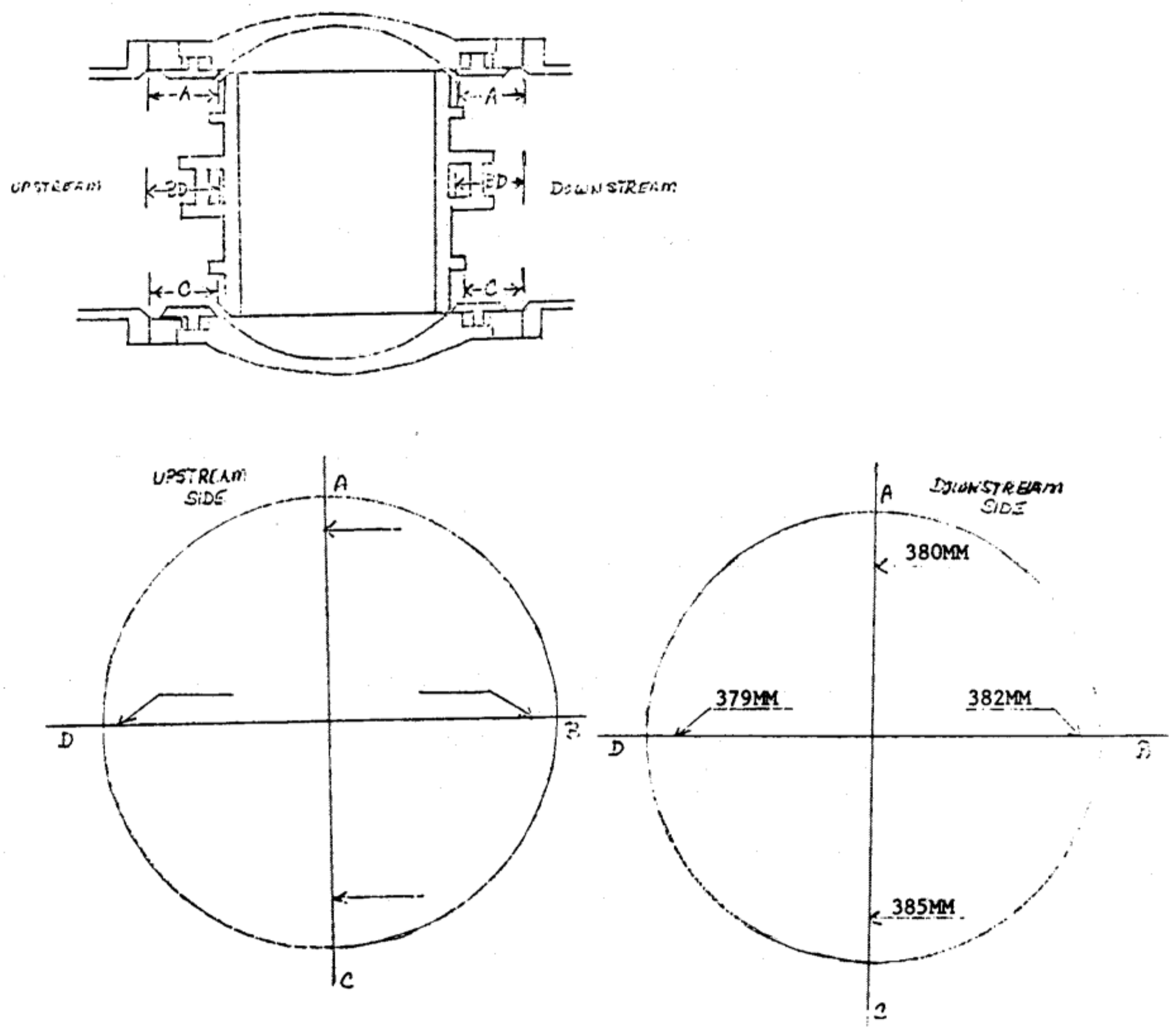
Date 10-28-81

Checked By WB

#32

UNIT # 2

Distance Between Surface of Valve Seal & Flange Body
Spherical Valve



GEN. HRS. 11317.8
GEN. SPIN 57.2
PUMP HRS. 13671.7
PUMP SPIN 61.7

Checked by GS DW Date 10-13-81
BC O&M 329

#32A

UNIT # 2
Oil Level Annunicators & Level Gages

Brg.	ANN.		Date Checked	Checked By
Jpper Guide Brg. 71QGB1HX	High Level & Trip	Set at 76 MM Above Normal Stop Level	10-23	RV RP

Remarks:

Upper Guide Brg. 71QGB2LX	Low Level & Trip	Set at 40 MM Below Normal Stop Level	10-23	RV RP

Remarks:

Thrust Brg. 71QGB2HX	High Level & Trip	Set at 148 MM Above Normal Stop Level	10-23	RV RP

Remarks:

Thrust Brg. 71QGB2LX	Low Level & Trip	Set at 65 MM Below Normal Stop Level	10-23	RV RP

Remarks:

PT Guide Brg. 71QTBH	High Level & Trip	Set at 47 MM Above Normal Stop Level	10-23	RV RP

Remarks:

PT Guide Brg. 71QTBL	Low Level & Trip	Set at 11 MM Below Normal Stop Level	10-23	RV RP

Remarks:

Gen Hrs. 11317.8
Gen Spin 57.2
Pump Hrs. 13671.7
Pump Spin 61.7

#33

Checked by RV RP Date 10-23-81

BG O&M 330

UNIT # 2
Annual Governor Maintenance Report

Checked restoring cable Yes ok.

2. Checked two pressure gages; Tank & Cabinet Yes ok.

3. Check four low oil pressure switches:

# 1 Closes at	310	Normal	# 1 Resets at	320	Normal
	310	As Found		321	As Found
	310	Set To		321	Set To
# 2 Closes at	308	Normal	# 2 Resets at	320	Normal
	308	As Found		320	As Found
	308	Set To		320	Set To
# 3 Closes at	290	Normal	# 3 Resets at	300	Normal
	290	As Found		300	As Found
	290	Set To		300	Set To
# 4 Open at	313	Normal	# 4 Resets at	325	Normal
	313	As Found		325	As Found
	313	Set To		325	Set To

4. Check air (brake) switches:

63BA-1 Air Switch Closes & below at	90	Normal	63BA-1 Switch Opens above	90	Norma
	87	As Found		90	As Fo
	87	Set To		90	Set T
63BA-2 Air Switch Closes & above at	20	Normal	63BA-2 Switch Opens below	20	Norma
	24	As Found		16	As Fo
	24	Set To		16	Set T.

5. Low pressure annunicator comes in at 300 psi Normal
298 psi As Found
298 Set To

Low pressure annunicator clears at 310 psi Normal
309 psi As Found
309 Set To

A-Pump lead position starts at	320	psi Normal	Stops at	350	psi Normal
	318	psi As Found		350	psi As Found
	318	psi Set To		350	psi Set To
B-Pump lead position starts at	320	psi Normal	Stops at	350	psi Normal
	318	psi As Found		351	psi As Found
	318	psi Set To		351	psi Set To
A-Pump lag position starts at	310	psi Normal	Stops at	335	psi Normal
	308	psi As Found		335	psi As Foun
	308	psi Set To		335	psi Set To
B-Pump lag position starts at	310	psi Normal	Stops at	335	psi Normal
	300	psi As Found		340	psi As Found
	300	psi Set To		340	psi Set To

#34.

Checked By Dug. DW WB Date 10-30-81

RC OSM 338

UNIT# 2
COOLING WATER FLOWS

ANN. Settings

80 WGA
Air Coolers
Normal Flow - 2600

	High	Low
Should be	1800	1300
As Found	1800	1200
Set To		1200

Manometer Differential Settings

	2000	3000
Should be	9.5	21.7
As Found	9.5	21.7
Set To		

80 WGTB
Thrust Brg Cooler
Normal Flow - 1070

	High	Low
Should be	750	535
As Found	800	535
Set To	750	

Manometer Differential Settings

	500	1000
Should be	3.96	15.1
As Found	3.7	15.2
Set to		

80 WGUB
Upper Guide Brg.
Normal Flow - 30

	High	Low
Should be	21	15
As Found	21	15
Set To		

Manometer Differential Settings

	25	50
Should be	1.0	4.2
As Found	1.0	4.2
Set To		

80 WTSP-1
Packing Box
Normal Flow - 45

	High	Low
Should be	36	19
As Found	36	19
Set to		

Manometer Differential Settings

	50	75	25
Should be	7.95	18.1	1.75
As Found	8.0	18.1	1.9
Set To			

80 WTSU
PT Runner Seal
Normal Flow - 92

Should be	62
As Found	58 * adjusted
Set To	60

Manometer Differential Settings

	75	112
Should be	8.1	17.9
As Found	7.9	17.9
Set To		

80 WTSL
PT Runner Seal
Normal Flow - 92

Should be	62
As Found	62
Set To	

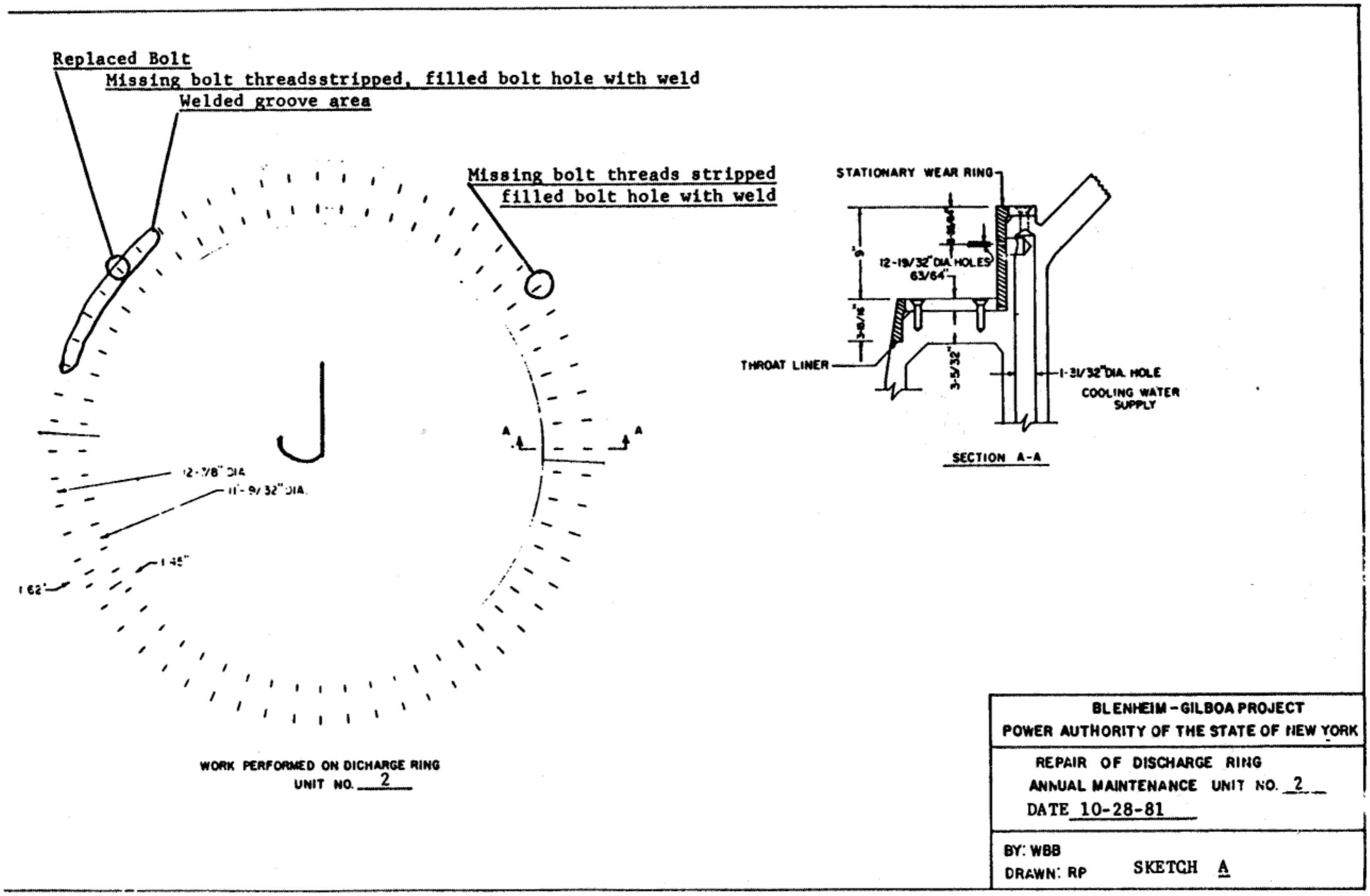
Manometer Differential Settings

	75	112
Should be	8.1	17.9
As Found	8.1	18.0
Set To		

Gen Hrs. 11317.8
Gen Spin 57.2
Pump Hrs. 13671.7
Pump Spin 61.7

Checked by WP S. Dow Date 10-29-81
BG O&M 331

#35


Replaced Bolt
Missing bolt threadsstripped, filled bolt hole with weld
Welded groove area
Missing bolt threads stripped
filled bolt hole with weld
12-7/8" DIA
11-9/32" DIA.
1.45"
1.62"
A
A
WORK PERFORMED ON DICHARGE RING
UNIT NO. 2
STATIONARY WEAR RING
12-19/32" DIA. HOLES
63/64"
9"
3-15/16"
3-5/32"
THROAT LINER
1-31/32" DIA. HOLE
COOLING WATER SUPPLY
SECTION A-A
BLENHEIM - GILBOA PROJECT
POWER AUTHORITY OF THE STATE OF NEW YORK
REPAIR OF DISCHARGE RING
ANNUAL MAINTENANCE UNIT NO. 2
DATE 10-28-81
BY: WBB
DRAWN: RP
SKETCH A

UNIT # 2
THRUST BRG. AND LOWER GUIDE BRG.
SHUT DOWN RELAYS, DIAL THERMOMETERS, R.T.D.'s

SHUT DOWN RELAYS

T ..st Brg. TT-1 38GTB

Required Trip 105°c

Oil Bath Temp. 109.5 1st.try 106 2nd. try

Annunciation ✓

Lower Guide Brg. LT-1 38GGB2

Required Trip 105°c

Oil Bath Temp. 104°C

Annunciation ✓

Dial Thermometers

Lower Guide Brg. Shoe# 2

Dial Indicator 47.5 adjusted 53/56.5 65° ANN.

Oil Bath Temp. 49.2 56.1/56 65 ✓

T ..st Brg. Temp. Shoe# ____

Dial Indicator 55.8 adjusted 68/65 68° ANN.

Oil Bath Temp. 55.8 64/65 69 ✓

G/M Lower Brg. Cooling Water Discharge

Dial Indicator ____ ____ 40° ANN.

Oil Bath Temp. DOES NOT WORK ____

Lower Brg. Oil Reservoir

Dial Indicator ____ 50 55° ANN.

Oil Bath Temp. ____ 50.5 55.3 ✓

G/M Cooler Discharge Temperature

Dial Indicator ____ 26 40° ANN.

Oil BathTemp. ____ 26 43.2 ✓

* Remarks Adjusted.Recorder RTD's read at least 2° lower then oil temp. bath W/recorder calibrated

(25108.5)

Gen. Hrs. 11317.8 Pump Hrs. 13671.7

Gen. Spin 57.2 Pump Spin 61.7

#7

R.T.D.'s

Lower Guide Brg. Pt.# 2 Shoe# 10

Recorder Temp. ____ 58 70° ANN.

Oil Bath Temp. ____ 59 71 ✓

Lower Guide Brg. Computer Shoe # 3

Computer Temp. ____ 63 - ANN.

Oil Bath Temp. ____ 63.7 - ____

Lower Guide Brg. & Thrust Brg. Oil Reservoir

Computer Near Shoe # ____

Computer Temp. ____ 64.2 ____ ANN.

Oil Bath Temp. ____ 65.1 ____ ____

Lower Guide Brg. & Thrust Brg. Oil Reservoir

Rec. Pt.# 7 Near Shoe # 9

Recorder Temp. 45.8 55 70° ANN.

Oil Bath Temp. 45.8 55.5 70 ✓

Thrust Brg. Pt. # 3 Shoe # 3

Recorder Temp. ____ 66.5 70° ANN.

Oil Bath Temp. ____ 68.5 72 ✓

Thrust Brg. Pt.# 11 Shoe # 4

Recorder Temp. ____ 45.5 70° ANN.

Oil Bath Temp. ____ 46.9 71.4 ✓

Thrust Brg. Pt.# 12 Shoe # 11

Recorder Temp. 45.2 67 70° ANN.

Oil Bath Temp. 46.4 69 72 ✓

Thrust Brg. Computer Shoe # ____

Computer Temp. ____ 46.6 ✓ ANN.

Oil Bath Temp. ____ 47.5 ✓ ____

Checked By WP GW

Date 10-16-81

BGOM-343

UNIT # 2
TURBINE GUIDE. BRG. AND SHAFT PACKING BOX
SHUT DOWN RELAYS, DIAL THERMOMETERS, R.T.D.'s

SHUT DOWN RELAYS

Temp. Relay Brg. Shoe Shoe# 5

Required Trip 75°

Oil Bath Trip 100° 1st. try
76° 2nd. try

Annunciation ✓

Excessive Relay Temp. Shaft Packing Box

Required Trip 75°

Oil Bath Trip Not tested

Annunciation Not tested

DIAL THERMONETERS

Oil Reservoir Temp. Near Shoe # 9

Dial Indicator		40°	55°	ANN.
.l Bath Temp.		41	55.5	✓

Bearing Shoe Temp. Shoe # 11

Dial Indicator	46	55	65°	ANN.
Oil Bath Temp.	46	56	65	✓

Shaft Packing Box Temp.

Dial Indicator	50	59.5	65°	ANN.
Oil Bath Temp.	50	60	65	✓

(25108.5)

Gen. Hrs. 11317.8

Gen. Spin 57.2

Pump Hrs. 13671.8

Pump Spin 61.7

R.T.D.'s

P.T. Brg. Computer Shoe# 2

Computer Temp.			64°	ANN.
Oil Bath Temp.			64°	

P.T. Brg. Pt.# 5 Shoe# 8

*Recorder Temp.	54	64/68	70°	ANN.
Oil Bath Temp.	59	68/72	74°	✓

* Remarks Checked recorder Cal.
* Adjusted. Checked W/bridge and
readings were 58.3/58.6
Problem is in recorder end.

Checked By WP BL MG GW Date 10-15-81

BGOM-355

#17

UNIT # 2
Annual Governor Maintenance Report

6. Alarms:
71QG#3 High Level sump comes in at 14" Normal
15" As Found
15" Set To

71QG#1&2 Low Level sump comes in at 4" Normal
4-1/2"As Found
4-1/2"Set To

7. Checked unloading valve assembly #A Pump Next year.

8. Checked unloading valve assembly #B Pump Next year.

9. Checked unloading valve assembly safety blows at:
A- Pump 370/375 Normal
371 As Found
371 Set To

B-Pump 370/375 Normal
371 As Found
371 Set To

10. Checked oil sump for dirt and Clean Not bad.

11. Checked oil tank clapper valve Operates ok.

12. Checked inside and clean oil tank. Very dirty

13. Took oil sample No.

14. Gen. air brake supply line moisture trap clean Yes ok (very little moisture)

15. Clean governor and brake poro stone filters Yes .

16. Clean all gauge faces and glass Yes.

17. Clean or change filters Changed pump filters and left side MPV.

18. Check entire unit for oil leaks Yes.

19. Check entire unit for air leaks Yes.

20. Check fór loose nuts and bolts, tighten as neccessary Yes.

21. Check both main and auxiliary valve nuts in sump and tighten Yes ok.

22. Check pressure by-pass valve Ok.

23. Check holes in main relay lines in sump for being plugged off tight with tapered pins Yes.

Checked By: Dug DW WB Date 10-30-81
BGO&M-339

FF 3-1

UNIT # 2

Annual Governor Maintenance Report

24. Remove, clean and lubricate linkages Yes.

25. Check all 90K pins to be normal Yes.

26. Clean all speed level and droop gears Yes.

27. Clean droop fulcrum and droop ball & socket Yes.

28. Check main pilot valve & bushing & hone if neccessary Yes. Replaced pilot valve housir

29. Check pilot valve pivot pin adjustment Yes.

30. Remove relay valve & inspect Moves up and down freely.

31. Inspect relay valve bushing Next year.

32. Check relay valve bushing clamps to be tight nest year.

33. Hone edges of floating lever connecting rod Edges are ok.

34. Inspect main valves, rings & bore every two (2) years Next year.

35. Check orifice in valve position gauge Yes.

36. Che:k brake pressure gauge and align Yes.

37. Clean compensating dashpot assembly Yes.

38. Check dashpot by-pass needle adjustment One turn open.

39. Fill compensating dashpot with oil with small plunger removed Yes.

40. Compensating dashpot small plunger measurement, check to be exactly 2-7/8" from top of bonnet to center line of small rod end pin 2-7/8" ok.

41. Check governor dashpot small plunger adjustment to be 40 sec. or more for last .100 rise with needle valve closed 3 min. 20 sec.

42. Check dashpot needle valve adjustment 3/16" open

43. Check compensating crank adjustment 90%

44. Check restoring pivot pin adjustment Set at 20.

45. Disassemble & clean & realign ballhead Next year.

Checked By: Dug. DW WB Date: 10-30-81

BGO&M-340

#34

UNIT # 2
Annual Governor Maintenance Report

46. Check ballhead bearings Minimal run out.

47. Clean ballhead dashpot & fill with 7/8oz. of dashpot oil Yes Adjusted run out to .004.

48. Check restoring cable connections Yes.

49. Open and check restoring cable shives Open three (very good condition)

50. Clean restoring cable shives & grease if needed Greased all

51. Check servo pressure lines & tignten flanges Yes.

52. Check snubber in pressure gauge line Yes cleaned.

53. Checked A pump flange gaskets to valve shutoff Yes.

54. Checked B pump flange gaskets to valve shutoff Yes.

55. Pump A unloading pressure switch calibrated:

	Low 80/100 Normal	High 255/260 Norm
As Found	90	260
Set To	90	260

56. Pump B unloading pressure switch calibrated:

	Low 80/100 Normal	High 255/260 Norm
As Found	80	260
Set to	80	260

57. Removed pump pilot valve A & cleaned & oiled Yes (very dirty)

58. Removed pump pilot valve B & cleaned & oiled Yes (very dirty)

59. Alignment readings:

Black Hand On	Red Hand On	Servo On
0%	%	-.5 %
20%	18.5 %	20 %
30%	29.5 %	29.5 %
40%	40 %	39.5 %
50%	51 %	49 %
60%	61.5 %	59 %
70%	72 %	69 %
80%	82.5 %	78.5 %
90%	92.5 %	88.5 %
100%	100+ %	95 %

60. Low brake air annunicator comes in at 90 Lbs. Normal
____ As Found
____ Set to

61. Check oil motor vibrator at 575 RPM Adjusted from 640

X 62. Adjust vibration no relay valve to be .006 to .007 .006

Checked By Dug. DW WB Date 10-30-81

#34

BGO&M-34D-A

UNIT # 2
Annual Governor Maintenance Report

64. Check 0 droop on connecting rod with dial indicator not to move when swinging gates ✓

65. Start unit but do not synchronize ✓

66. Move speed no load solenoid out electrically ✓

67. Move gate limit to 50% ✓

68. Set 0 droop and 0 speed level

69. Set droop to 4 ✓

70. Set speed adjust to 0 load ✓

71. Mark pre positioning of speed adjust ✓

72. Set speed no load solenoid to be sure out of way ✓

73. Adjust dashpot needle valve on start so unit does not hunt ✓

OPEN GATE TIME MAIN VALVE 30%-80% ORIGINAL 10 Sec.

FOUND 9.6 Sec.

CLOSING TIME MAIN VALVE GATE LIMITER #2 80% to 30% ORIGINAL 28 Sec.

FOUND 26 Sec.

Checked By Dug. DW WB Date 10-30-81
BGO&M-340-13

#34

SCHEDULE PERIOD AND INSPECTION STANDARD

Part	Schedule Period Regular Inspection: Period (yrs)	Schedule Period Regular Inspection: Item of Inspection	Schedule Period Detail Inspection: Period (yrs)	Schedule Period Detail Inspection: Item of Inspection	Remarks
Major Turbine					
Runner	2	Leakage, corrosion, deterioration inspection	5-10	Runner disassembly inspection	
		Runner clearance of liner measurement (in Kaplan type exterior clearance of runner)			
		Runner boss oil leaks, saturation of water inspection			
		Inspection of runner boss oil supply			
Wicket Gate Mechanism	2	Inspection of leakage, corrosion and wear	5-10	Operating mechanism disassembly	
		Measure wicket gate gap			
		Measure servomotor stroke vs. wicket gate opening (in Kaplan - runner vane opening)			
Spiral Case (incl. speed ring, stay vane and upper and lower cover draft tube liner)	2	Leakage, corrosion, deterioration, stain (corrosion) inspection	5-10	Upper cover disassembly inspection	
				Draft tube liner inspection	
Bearing	2	Exterior overall inspection	5-10	Bearing disassembly inspection	
		Bearing gap measurement	When Necessary	Oil pipe cooling water pipe interior inspection	
		Thermometer, temperature RY test, oil level, water tie RY action test, measurement of bearing oil supply, measurement of cooling water quantity			
Main Shaft	2	Exterior overall inspection	5-10	Inspection of leakage of runner seating part	
			When Necessary	Interior failure check Measurement of staft vibration	
Shaft Seal	2	Disassembly inspection			

SCHEDULE PERIOD AND INSPECTION STANDARD

Part	Schedule Period Regular Inspection: Period (yrs)	Schedule Period Regular Inspection: Item of Inspection	Schedule Period Detail Inspection: Period (yrs)	Schedule Period Detail Inspection: Item of Inspection	Remarks
Major Turbine (Cont'd.)					
Governor	2	Exterior overall inspection Measurement of lacing, jumping	5-10	Pressure distributing valve dash pot, servomotor, converter, pilot valve, and other disassembly inspections	
	When Necessary	Measurement of all kinds of limit switch operating limits; measurement of frequency; measurement of speed regulation percent; measure opening width at start, unloading opening width; vacuum tube characteristic test	When Necessary	Measurement of characteristic of actuator cycle; measurement of speed characteristics; measurement of speed vibration pilot valve; measurement of pressure distributing valve gap; gap measurement of whole open and close mechanism; measurement of stable band	
Pressure Regulator	2	Inspection of leakage deterioration, wear, stain on valve body or valve disc Inspection of dash pot Restoring movement Inspection of operating mechanism	5-10	Pressure distributing valve, dash pot, disassembly check, operating mechanism disassembly check, servomotor disassembly check	
Inlet Valve (incl. bypass valve)	2	Inspection of switch, pressure distributor limit switch, leakage check, exterior overall inspection	When Necessary	Disassembly check for open and close mechanism - overall check for other parts, such as servomotor, pressure distributor, pressure distributing valve disassembly check Valve seat check Open-close movement inspection Leakage check of valve body, valve disc, bypass valve, valve body pipe Check corrosion (deterioration) wear, stain, unloading disassembly, pressure oil pump	Steel pipe valve
Pressure Oil Equipment	2	Unloading, disassembly movement test Safety valve movement test Oil pressure RY movement test Oil reservoir interior inspection Measurement of loading time	5-10	Unloader oil surface adjusting equipment, safety valve, etc. disassembly inspection	
			When Necessary	Measuring of pressure oil pump discharge quantity measurement of pressure oil tank oil leaks Gas leaks Measurement of pressure oil system oil leaks quantity Quqntity of pressure oil tank Oil pressure of pressure oil tank, oil level setting adjustment test	

SCHEDULE PERIOD AND INSPECTION STANDARD

Part	Schedule Period Regular Inspection: Period (yrs)	Schedule Period Regular Inspection: Item of Inspection	Schedule Period Detail Inspection: Period (yrs)	Schedule Period Detail Inspection: Item of Inspection	Remarks
Major Turbine (Cont'd.)					
Lubricating Oil Equipment	2	Oil surface shutdown Oil RY movement test Safety valve for grease switchover valve movement check. Strainer disassembly inspection Lubrication oil system exterior inspection - oil reservoir interior inspection - grease distributing valve disassembly inspection	When Necessary	Measurement of lubricating oil pump discharge quantity. Measurement of lubricating oil supply quantity; lubricating pump disassembly inspection	
Pressure Oil Lubricating Oil	2	Oil quality inspection Purify oil			
Water Supply and Drain Equipment	2	Strainer disassembly inspection Safety valve motion test; water surface water flow; RY motion test pump foot valve inspection supply water reservoir interior inspection	5-10	Pump disassembly inspection	
			When Necessary	Pump discharge flow quantity measurement - spending water quantity Water tank leaks measurement Pressure regulating equipment disassembly inspection	
Compressed Air Equipment					As air compressor equipment for break
Special Tests					Overhaul
Output Test	When Necessary				Runner repair shall be done at exchange time
Efficiency Test	When Necessary				
Load Rejection Test	When Necessary				After repair governor. Pressure regulator disassembly and turbine generator overhaul.
Measurement of Vibration	When Necessary				Deal at overhaul runner repair replace time. Measurement condition and measurement instrument should be same.

SCHEDULE PERIOD AND INSPECTION STANDARD

Part	Schedule Period Regular Inspection: Period (yrs)	Schedule Period Regular Inspection: Item of Inspection	Schedule Period Detail Inspection: Period (yrs)	Schedule Period Detail Inspection: Item of Inspection	Remarks
Main Generator					
Stator	2	Exterior overall inspection Insulation resistance measurement	When Necessary	Insulation deterioration measurement	
Rotor	2	Exterior overall inspection Insulation resistance measurement	5-10	Rotor lift up and disassembly inspection	
Excitation Equipment	2	Exterior overall inspection (collector ring, rectifier FIELD-POLE coil static excitation equipment, field winding resistor, field winding switch) insulation resistance measurement			
Bearing	2	Exterior overall inspection	5-10	Bearing disassembly inspection Bearing clearance measurement	
		Oil surface water tie RY motion test	When Necessary	Oil pipe, cooling water pipe interior inspection, shaft current measurement	
Main Shaft	2	Exterior overall inspection	When Necessary	Shaft vibration measurement	
Brake Equipment	2	Exterior overall inspection Brake shoe Wear measurement	5-10	Cylinder disassembly inspection	Exterior inspection should include leaks of gas and oil
Ventilating, Cooling, Dehumidifying, and Fire Equipment	2	Exterior overall inspection	When Necessary	Equipment, piping interior inspection	
Automatic Voltage Regulator	2	Exterior overall inspection Inspection and test for accessory switch, reset	When Necessary	Characteristic measurement	

SCHEDULE PERIOD AND INSPECTION STANDARD

Part	Schedule Period Regular Inspection		Schedule Period Detail Inspection		Remarks
	Period (yrs)	Item of Inspection	Period (yrs)	Item of Inspection	
Phase Control Thyristor					
Main Part Relationship					Same as generator inspection item
Side Part Opening	2	Interior inspection Rectifier, brush inspection Measurement of wear quantity			
Auxiliary Part Relationship					Auxiliary parts include lubricating equipment, water supply and drain equipment, gas control equipment, excitation equipment, period of inspection same as auxiliary part of turbine generator
Main Power Transformer					
Main Body (core?) Windings Bushing Accessory	2	Exterior overall inspection Check alarm contact point Insulation resistance measurement (including control circuit, low voltage circuit); inspection of main body of open type	When Necessary	Disassembly inspection of oil pump, cooling form, etc.	
Insulating Oil	2	Voltage measurement of insulating destruction Oil quality check Analyze gas in the oil			But transformer for super-high voltage large size at least once a year need to check insulating oil - oil quality and analyze gas inside the oil
	When Necessary	Purify oil			
Load Tap Changers	2	Exterior overall inspection Motion confirmation of control switches Relays Insulation resistance measurement of control circuit - low voltage circuit	5 yrs or 5000 times	Interior inspection; check wear and others of power transmit parts	
	When Necessary	Oil change or purify			Insulation oil inspection - determined by the result of daily inspection at least once a year need to purify oil if used often

SCHEDULE PERIOD AND INSPECTION STANDARD

Part	Schedule Period Regular Inspection: Period (yrs)	Schedule Period Regular Inspection: Item of Inspection	Schedule Period Detail Inspection: Period (yrs)	Schedule Period Detail Inspection: Item of Inspection	Remarks
Circuit Breaker					
Main Tank (bushing part interrupt)	3	Exterior overall inspection Blow-out valve inspection Insulation resistance measurement	6 yrs or 6000 times	Disassembly interrupt parts (check all parts by demand) Renew the consumables	If exceed 5 times break operation @ 70% specified capacity, should have disassembly inspection during short circuit I have an obviously shock, or happened 5 or 6 times light short circuit - also required to have inspection in details Packing gasket spring microsnit - they are belong to the article of consumption
Operating Mechanism (control circuit air system)	3	General inspection - operating test - Min. switch motion test - measure times needed for open 3-phase un-balance measurement Insulation resistance measurement Pressure gauge adjusting test Leaks check	6 yrs or 4000 times	Disassembly inspection Adjusting of connecting rod, buffer mechanism, operating cylinder, rod guide Renew consumables	
Insulating Oil	When Necessary	Insulation destructive voltage measurement Oil purification			If circuit breaker interrupt motion exceeds 8000 times renew interrupt blow-off valve - control block and other parts of operating mechanism
Air Compressor Equipment	3	Exterior overall inspection Safety valve Pressure - pressure reducing valve operation test Piping inspection Pressure gauge adjusting Leaks test Insulation resistance measurement	3-5	Disassembly inspection All kinds test	

SCHEDULE PERIOD AND INSPECTION STANDARD

Part	Schedule Period Regular Inspection: Period (yrs)	Schedule Period Regular Inspection: Item of Inspection	Schedule Period Detail Inspection: Period (yrs)	Schedule Period Detail Inspection: Item of Inspection	Remarks
Circuit Breaker					
Operating Mechanism	3	Operating mechanism inspection Operating test Insulation resistance measurement (control circuit)	5-10	Dash pot All kind valve Operating mechanism Disassembly inspection	Include inspection of earthed mechanism
Interrupt Parts and Support Insulator	3	Interrupt part inspection Combination insulation/resistance measurement			
Arrester	1	Exterior overall inspection Insulation resistance measurement Movement indicator circuit inspection			Check during season of lightning
High Voltage Mercury Rectifier	1/2	Exterior inspection	1	Characteristic test Auxiliary disassembly inspection Inspection resistance measurement	
Switchboard					
Cubicle Circuit	2	Transformer secondary circuit control circuit, isolation resistance measurement Control circuit - sequence test All kinds alarm Indicating test Inspection for all kinds control RY Inspection for all kinds switches Check alignment and tighten terminal			
Meter (incl. recorder)	5	Insulation resistance measurement Adjusting test Calibration test	5-10	Disassembly inspection of recorder	Ampere meters at according to meter equipment manual and instruction

SCHEDULE PERIOD AND INSPECTION STANDARD

Part	Schedule Period Regular Inspection: Period (yrs)	Schedule Period Regular Inspection: Item of Inspection	Schedule Period Detail Inspection: Period (yrs)	Schedule Period Detail Inspection: Item of Inspection	Remarks
Switchboard (Cont'd.)					
Sequence Protective Relay Equipment	1				
Protection of Power Transmission Relay		Secondary synthesize test Load measurement Insulation resistance measurement			Secondary general test may be substituted by simple substance characteristics direct current sequence test (period of 1 year)
Mainline Protection Relay Equipment System Operation Equipment		Direct current sequence test Insulation resistance measurement			Complete static equipment can use simple test
System Out of Order Automatic Recording Equipment	1	Check motor brush Change speed; decrease machine oil Change ink; lubricating	2-3	(Over Whole) Renew rubber roller, bearing, motor, record, drum check (renew when it is necessary)	
Machine Protection and Other	2	Simple substance characteristics Direct current sequence test Insulation resistance test			
Monitoring Control Equipment	2	System panel control table Situation interpretation panel (include civil item) Effective power control equipment, etc. Control circuit Sequence test Indicative test control RY Switches, terminal alignment check Insulation resistance measurement Meter adjusting test, etc.	When Necessary	Characteristics test	
Information Display	3-1	Concerning central dealing and surrounding machine have switch, lamp, fan; check, clean and lubrication - voltage margin test - measure all kinds wave, level measure, alarm motion test, general test for whole system	When Necessary	Program test Mechanism disassembly check	
Remote Control Equipment	2	Selection indicating test Measurements of equipment insulation resistance			Information conveyance equipment by communication equipment O&M manual

SCHEDULE PERIOD AND INSPECTION STANDARD

Part	Schedule Period Regular Inspection		Schedule Period Detail Inspection		Remarks
	Period (yrs)	Item of Inspection	Period (yrs)	Item of Inspection	
Power Control Transformer (for gauge)	3	Exterior overall insulation resistance measurement	When Necessary	Same as transformer inspection item	
Power Condenser	3	Exterior overall inspection Insulation resistance measurement	When Necessary	Insulation deterioration measurement	
Reactor (incl. DC reactor)					Periodic inspection items same as transformer
Battery			When Necessary	Quantity measurement	
Charger (incl. rectifier)	3	Exterior overall inspection Insulation resistance measurement Confirm alarm indication			
Main Line	3	Exterior overall inspection Support insulator, insulating tube, etc. Need to clean and check			
	When Necessary	Check wire and insulator Check and wiring wire connection			For enclosed main line estimate after begin to use 1 year
Power Cable	3	Check build situation Insulation resistance measurement Check coil terminal connection			
Steel Structure	When Necessary	Check material corrosion damage Check loose bolt Check leg unbalance and sinking			
Neutral Point Earth Resistor	3	Exterior overall inspection Insulation resistance measurement			
Related to Communications					Apply communications equipment O&M manual

SCHEDULE PERIOD AND INSPECTION STANDARD

Part	Schedule Period Regular Inspection		Schedule Period Detail Inspection		Remarks
	Period (yrs)	Item of Inspection	Period (yrs)	Item of Inspection	
Others					
Lighting, Electric Heat Circuit (incl. dormitory)	1	Insulation resistance measurement			
Related Dam Water Flow Electrical Equipment	1	Objects are control panel, motor, etc. Inspection content same as ________			
Alarm Equipment for Open Gate Test	1	General motion test			
Spare Electrical Source Equipment	1	General inspection and test run	5-10	Every part disassembly inspection	Equipment for dam should be finished; regular inspection before flood season
Power Distribute Line	1	Special inspection			After storm check at proper time
Crane Elevator					According to labor safety code

Appendix G

PUMPED STORAGE BIBLIOGRAPHY

In the course of the preparation of this report, a number of papers on pumped storage were obtained and studied. The following list is a bibliography of the papers that have come to the attention of investigators.

"A 292 MW Pumped-Storage Plant Under Construction in Ireland." Water Power, 1972.

Ackerman, A.J. "Hydroelectric Power in the U.S." Water Power, November 1968, Vol. 20, pp. 439-444.

Ackerman, A.J. "New Opportunities in Pumped-Storage." American Power Conference, Vol. 20, pp. 385-389.

Aeberli, A.E. "Deraiz-Type Reversible Pump-Turbine Installation at Sir Adam Beck-Niagara Forebay Storage Project." ASME Transactions, December 1959, Series D, pp. 505-520.

Alexander, J.L. "Ontario Hydro Sir Adam Beck-Niagara Pumping Generation Station." Edison Electric Institute, Hydraulic Power Committee, May 1956, Appendix G.

Alexander, R.K. et al. "Startup and Initial Operation Blenheim-Gilboa Pumped Storage Project." IEEE, May 1974.

Allen, P.E., and Larson, W.E. "Underground Energy Storage." EEI, May 31, 1974.

Allner, F.E. "Hydraulic Turbine and Pump Combined in a Single Unit." Power, Vol. 76, pp. 266-267.

Amberg, E.J. "Rock River Hdyroelectric Development of the Connecticut Light and Power Co." AIEE Transactions on Power, Apparatus and Systems, Vol. 47, pp. 1100-1107.

Angelin, A.B. "Energy Regulation in Large Power Systems by Pumping Stations." IEEE Transactions on Power, Apparatus and Systems, Vol. 89, pp. 2079-2088.

Annett, F.A. "Pumped-Storage Hydroelectric Plants." Power, Vol. 78, pp. 20-24.

Armbruster, T.F. "Generator-Motors for Reversible Pump-Turbines." Allis-Chalmers Press, May 1961.

Armbruster, T.F. "Pumped-Storage - A New Power Source." Water Power, Vol. 12, pp. 147-152.

Armbruster, T.F. "Raccoon Mountain Generator-Motors." Allis-Chalmers Engineering Review, Vol. 35, No. 2.

Armbruster, T.F. "Static Converter Starting of Large Pumping Units." Allis-Chalmers Engineering Review, 1972.

Arthur, H.G. "Progress at the Mt. Elbert Pumped-Storage Power Plant in Colorado." Water Power, Vol. 26, pp. 197-204.

Arvanitidis, N.V. and Rosing, H. "Composite Representation of a Multireservoir Hydroelectric Power System." IEEE Transactions on Power, Apparatus and Systems, Vol. 89, pp. 319-326.

"Back-to-Back Starting of Pump-Turbine Sets," Water Power, August 1968, pp. 332-333.

"Bajina Basta Converts to Pumped-Storage," Water Power and Dam Construction, November 1977.

Baker, D.H. and Whippen, W.G. "Trends in Selection of Turbo Machinery for Pumped-Storage." Energy Foundation Conference, August 1974.

Barker, G. "Centralized Power Control of 65,000-Horsepower Pump Motors at Grand Coulee Dam." IEEE Transactions on Power Apparatus and Systems, Vol. PAS-86, No. 11.

Barker, G.R. Jr. "Operating Experience with Large Pumps at Grand Coulee Dam, Washington." American Power Conference, Chicago, March 1958.

Barrett, S. "Black Saturday at Northfield Mountain." Electric Light and Power, June 1972, pp. 51-52.

Bates, C.G. "Bureau of Reclamation Pumped Storage Plants." ASCE, Memphis, Tennessee, January 1970.

"Bath Country Fact Sheet," Virginia Electric Power Company.

Baumann, K.M.J. "Design Concept of the Single-Shaft, Three-Unit Set of Waldeck II Pumped-Storage Power Station." Escher Wyss News, 1972.

Bernard, P.J. et al. "Method for Economic Scheduling of a Combined Pumped Hydro and Steam Generating System." IEEE Transactions on Power, Apparatus and Systems, Vol. 84, pp. 23-30.

Bevc, F.P. "Hydro Generator Technical Presentation." EEI, June 1978.

Bevc, F.P. and Meehan, R.J. "Generator-Motors for Pacific Gas & Electric's Helms Pumped Storage Project." IEE Transactions, December 1980.

"Bibliography on Pumped Storage to 1975." IEEE Power Generation Committee, January 1976.

"Bids Opened on Smith Mountain Dam," Engineering News-Record, August 27, 1959, pp. 32.

Bilby, C.R. "Pumped-Storage and Actual Operations in a System." Engineering Foundation Conference, August 1974.

Blind, H. "Planning of Pumped-Storage Plants - Part 1." Water Power, June 1967.

Blind, H. and Dr. Ing. "Planning of Pumped-Storage Plants" Water Power, July 1967.

Booth, E.S. and Kennedy, G. "The Economics and Design of the Blaenan Ffestiniog Pumped-Storage Scheme." World Power Conference, 1958, Report No. 68A2/4.

Brackevitch, M. "Some British Developments in Large Plant for Hydro-Electric Power Generation." Fifth World Conference, Vienna, 1956, Section H, Paper 224H/37.

Braikevitch, M. "Pumped Storage Plant."

Brennan, F. L. and St. Onge, G.A. "Unique Electrical Design Features of the Northfield Mountain Pumped-Storage Project." IEEE, January 1969.

Brennan, F.L. "Start-up and Operating Performance, Northfield Mountain Pumped-Storage Project." IEEE Winter Meeting Conference, Paper C75-038-5.

Brown, C.B. and Tomsic, E.M. "Pumping-Generation Units for the Grand Coulee Pumping-Generating Plant." IEEE, June 1972.

Brown, P.G. "Reduced Voltage Starting Performance of Synchronous Condensers and Pumped Hydro Units." Joint Power Generation Conference, 1975, Paper PG 75643-7.

Brown, P.G. and Otte, G.W. "Electrical Design Consideration in Pumped-Storage Hydro Plants." IEEE Pacific Annual Meeting, Paper No. 63-1227.

Burdin, W.W. "Design of Carters Pumped-Storage Project." ASCE Proceedings, Vol. 96, PD3 No. 7353, pp. 383-400.

Burdin, W.W. "General Design of the Carters Pumped-Storage Project." ASCE Proceedings, Paper No. 7375, Vol. 96 P03.

Bussi, J.E. "Helms Pumped-Storage Project, Preliminary Study of Requirement for Pump-Start by Direct Connected Starting Motor." PG&E.

Buter, J. "Asynchronous Starting of a Pump-Turbine for Pumping Operation." Rheinisch-Westfalisches Elektrizitatswerk, Federal Republic of Germany.

"Cabin Creek Pumped-Storage Hydroelectric Project, Public Service Company of Colorado, Operation and Maintenance," EEI, Paper Presented to Hydraulic Power Committee, Atlanta, GA, April 1968.

"Calculations and Information Regarding Various Pump-Storage Schemes," Charles T. Main International, Inc., July 1972.

Calhoun, T.V., and Seidl, A.C. "Starting Reversible Pump-Storage Units by the Reduced Frequency, Reduced Voltage Method." International Conference on Pumped-Storage Development and Its Environmental Effects."

Calvert, J.D. "Pumped-Storage Hydro Facility Serves as Giant Storage Battery." Power Engineering, August 1963.

Canay, M. "Asynchronous Starting of a 230 MVA Synchronous Machine in 'Viaden 10' Pumped-Storage Station." Brown Boveri Review, July 1972, pp. 313-318.

Canay, M. "Partial Frequency Starting in Pumped-Storage Stations." Brown Boveri Review, July 1971, pp. 319-326.

Casacci, S. et al. "High-Head Pump-Turbines: French Experience." Water Power and Dam Construction, February 1983.

Cassapoglou, C. "A Method for the Economic Scheduling for Integrating Pumped-Storage Hydroelectric Plants into a Power." Symposium of Hydroelectric Pumped-Storage Schemes, Athens, November 1972.

Chacour, S.A. et al. "Design Considerations for a 1500 m Head 300-600 MW Double Stage Reversible Pump-Turbine with Regulator."

Chandrakis, M.S. "Combining Pumped-Storage and Thermal Power." Water Power and Dam Construction, October 1976.

Chapin, W.S. "Niagara Power Project." Civil Engineering, Vol. 31, pp. 36-39.

"Characteristic Features of Pumped-Storage Power Stations in Japan." World Power Conference Transactions, 1966, pp. 1149-1171.

Chatelain, J. and Simond, J.J. "Back-to-Back Starting of High Power Synchronous Motors for Storage Schemes." CIGRE, August 1974.

Chevalier, R.G. and Samois, R.P. "Start-Up and Preliminary Operation." American Power Conference, April 1975.

Ciarlini, R.M. and Jardao. W. "Pumped-Storage Development in Brazil." Water Power and Dam Construction, March 1981.

Cobian, M.J. "Optimal Pumped-Storage Operation with Interconnected Power Systems." IEEE Transactions on Power, Apparatus and Systems, Vol. 91, pp. 1391-1399.

Comninellis, E. "Ludington Pumped-Storage Project." ASCE Proceedings, Vol. 99, 9PO1, No. 7696.

Concordia, C., et al. "Synchronous Starting of Motor from Generator of Small Capacity." IEEE Transactions on Power, Apparatus and Systems, Vol. 86 No. 10, pp. 1215-1226.

"Congress Approves Niagara Project." Engineering News-Record, August 22, 1957, p. 27.

"Consumers Power Launches Huge Pumped-Storage Project." Electrical World, December 4, 1967, p. 25.

"Contract Let for Pump-Storage Project." Electrical World, January 4, 1960, p. 26.

Cooper, E.A. "Modern Hydraulic Generators." Power Engineering, August 1970.

Cooper, W.A. and Fukuda, Y. "Testing Hydraulic Generators." Power Engineering, August 1972.

Cox, E.T. "Pumped-Storage Generation Factors to be Considered." Engineering Foundation Conference, August 1974.

Crews, E.J. Jr. "Fairfield Pumped-Storage Project." Engineering Foundation Conference, August 1974.

De Carolis, F.J. et al. "Embankment Design and Construction for the Blenheim-Gilboa Pumped-Storage Power Project." Commission Internationale des Grands Barrages, March 1973.

De Siervo, F. and Lugaresi, A. "Modern Trends in Selecting and Designing Reversible Francis Pump-Turbines." Water Power and Dam Construction, May 1980.

DeFazio, F.G. "Transient Analysis of Variable-Pitch Pump-Turbines." University of Colorado, Civil Engineering Department, MS Thesis.

Denton, S.M. and Britt, H.O. "Pumped-Storage and Hydro Generation at Flatiron Power Plant." AIEE Transactions on Power, Apparatus and Systems, Vol. 74, No. 8, pp. 614-618.

Deriaz, P. "Comments on Hydraulic Paper No. 10 by Professor H. Addison on 'Pumping Problems - Present and Future'." Joint Meeting - Institute of Civil Engineers and Institute of Mechanical Engineers, May 1956.

Deriaz, P. and Warnock, J.G. "Reversible Pump Turbines for Sir Adam Beck-Niagara Pumping." ASME, Paper No. 58-A-108.

Dickenson, W.H. "Muddy Run Pumped-Storage." Electrical World, July 4, 1966, pp. 31-33.

Dickinson, M.L. "Fitting Pumped-Storage Into a Large Generation System." Electrical West, August 1962.

Dobson, F. "Sir Adam Beck, Niagara Generation Station No.2." ASCE Proceedings, Vol. 83 P05 No. 1419 pp.1-12.

Dobson, F. "Sir Adam Beck-Niagara Pumping Generation Station No. 2." ASCE Transactions, 1959, pp. 32-38.

Donovan, R.E. "Cornwall - Will It Ever Be Built?" Electrical World, March 1, 1971, pp. 36-39.

Donsky, B. "Complete Pump Characteristics and the Effects of Specific Speeds on Hydraulic Transients." ASME Journal of Basic Engineering, Transactions, Series D, Vol. 81, pp. 685-696.

Dowell, C.L. "Pump at Buchanan Dam Adds Peak Capacity to Power System." Power, August 1951, p. 55.

Drinnon, K.C., et al. "Remote Control of Tennessee Valley Authority's Raccoon Mountain Pump-Storage Plant." IEEE, PES Winter Meeting, Paper T 75-190-4.

Duckworth, J.C. et al. "Nuclear Generation and the Future Power System in Great Britain." 5th World Power Conference, Paper No. 194J 13.

Duncan, W. Jr. and Bates, C.G. "Selecting Large Pumping Units." U.S. Department of the Interior, Bureau of Reclamation.

Eick, R.W. and Shasky, A.R. "Castaic Power Project." IEEE Conference, Paper CP-564-PWR, July 1970.

"Electrical Design Features of Cornwall Station." EEI, St. Louis, September 1964.

Elliot, R.A. and Mattern, D.H. "Record-Size Pump Turbine to be Installed at TVA Hiwasee Project." Civil Engineering, March 1953, p. 56.

Engle, W.W. "Exploration and Investigation Program for the Raccoon Mountain Pumped-Storage Project." ASCE National Meeting, Phoenix, Arizona, January 1971.

Evans, R.K. "Pumped-Storage Hydro: New Plants Produce Competitive Peaking Power." Power, May 1966, pp. 191-198.

"Factors Governing Selection of a Large Pumped-Storage Project to Utility System Peak Loads." World Power Conference, Report No. 7, Melbourne, Australia, 1962.

Fahlbusch, F. "Economics of Pumped-Storage Projects." Morrison-Knudsen Engineers, Inc.

Ferecsik, J.J. and Vanbuskirk, W.H. "Electrical Design Aspects of Muddy Run Pumped-Storage Plant." IEEE Transactions on Power, Apparatus and Systems, Vol. 88, No. 8, pp. 1302-1309.

Ferreira, A. "Initial Operating and Testing Experience, Northfield Mountain Pumped-Storage Project." American Power Conference, May 1973.

Ferreira, A. and Carver, C.E. "The Importance to Utilities of Dynamic Duty Benefits from Pumped-Storage."

Ferreira, A. and Fisher, W.E. "Planning and Design." American Power Conference, April 1975.

"Ffestiniog - Britain's 320 MW Pumped-Storage Showcase." Electric Light and Power, November 1963, p. 56.

"Ffestiniog Pumped-Storage Development." Water Power, May and June 1963.

"First Pump-Turbine to be Installed in U.S. is Ordered by TVA." Electrical World, Vol. 138, p. 112.

Fisher, M.H., Fonesca, G.W. and Gilbert, S.M. "Design Features of Mt. Elbert Pumped-Storage Power Plant." IEEE Summer Meeting, 1975, Paper F75 443-2.

Fisher, R. K. and Degnan, J.R. "Advances in Pump-Turbin Design." Water Power and Dam Construction, April 1985.

Fitzgerald, J.A. et al. "Operation of Seneca Pumped-Storage Project." IEEE Transactions, Paper T 73-204-5, Vol. 92, pp. 1510-1516.

Fitzgerald, J.P. "Experience with Synchronous Starting of Motor-Generators for Seneca Pumped-Storage Plant." EEI, Oklahoma City, October 1971.

Fitzgerald, J.P., et al. "Synchronous Starting of Seneca Pumped-Storage Plant." IEEE Transactions on Power, Apparatus and Systems, Vol. 88 No.4, pp. 307-315.

"Flatiron Pump-Turbine Gives 'Big T' Water a Lift in the Colorado Rockies." Electrical World, Vol. 141, pp. 42-43.

"Flatiron Tests First U.S. Pump-Turbine." Power Engineering, September 1954.

Fleer, M.W. "Union Electric's Taum Sauk Project, Operation and Maintenance." American Power Conference, 1974.

Florjancic, D. "Problems in Starting-Up Large Pump-Turbines."

Florjancic, D. and Hartland, D. "Pump-Turbine Starting Characteristics" Water Power, January 1965.

Forgey, H.L. "Feasibility and System Planning - Symposium on the Ludington Pumped-Storage Hydroelectric Generating Station." American Power Conference, 1974.

Forgey. "Symposium on Pumped-Storage Hydroelectric Generating Station." American Power Conference, 1974.

Fox, B.M. "Overvoltages During Load Rejection at Northfield Mountain Pumped-Storage Plant." IEEE Summer Meeting, June 1969, Paper No. CP 642-PWR.

Frankhauser, H. and Trucco, G. "Economic Analysis of Swiss Pumped-Storage Schemes for Various Parameters of Operation and Energy Costs." International Conference on Pumped-Storage Development and Its Environmental Effects.

Freeman, W.W.K. "Pumped-Storage Hydroelectric Plants." ASCE Transactions, Vol. 94, PP. 884-935.

Friedlander, F.D. "Pumped-Storage - An Answer to Peaking Power."

Fukasu. "Experiences on Transients in Pump-Turbine Projects with Hydraulic Peculiarities." ASME. International Symposium on Waterhammer in Pumped-Storage Projects, November 1965.

Fulton, A.A., Haldane, T.G.N., and Mountain, P.W. "The Practical Application and Economics of Pumped Storage in Great Britain." Fifth World Power Conference, 1955, Vienna (No.227H/38).

Galloway, C.D. et al. "Role of Pumped-Storage in Generation Systems." American Power Conference, Vol. 26, pp. 954-964.

Gallowlay, C.D. and Ringlee, R.J. "Dispatching Pumped-Storage Scheduling." IEEE Transactions on Power, Apparatus and Systems, Vol. 85, PP. 459-465.

Gamble, G.P. "Pumped-Storage for Peaking Service-Development and Description of the Taum Sauk Project." American Power Conference Proceedings, Vol. 3, pp. 687-699.

Gamble, G.P. "Pumped-Storage Power Taum Sauk Plant near Lesterville, MO." Mechanical Engineering, Vol. 82, p. 89

Gamble, G.P. "Taum Sauk Will Provide 350 MW of Peaking Hydro." Union Electric Co., Electrical World, May 8, 1961.

Gamble, G.P. and Rudulph, E.A. "Pumped-Storage for Peaking Service, Taum Sauk Project - A Step Forward." American Power Conference Proceedings, Vol. 26, pp. 692-703.

Gaskins, R.W. "Taum Sauk Project Electrical Features." EEI, February 1961, St. Louis, Missouri.

Gawlowicz, B.S. "Yards Creek-Automated Pumped-Storage." IEEE Winter Meeting, 1965.

"Generator-Motor Problems in Pumped-Storage Installations." IEE Proceedings, Vol. 107, Part A, pp. 157-171.

Golze, A.R. "Edward Hyatt (Oroville) Underground Power Plant." ASCE Proceedings, Vol. 98, PO2, pp. 419-434.

Gove, G.E. "Taum Sauk Pumped-Storage Plant - A Review of the First Year and a Half of Operation." Arkansas-White-Red Basins Inter-Agency Comm., July 1965.

Graybill, H.W. "Grounding of Gas-Insulated Substations." Pennsylvania Electric Association, presented to the Electrical Committee, October 1974.

"Grimsel II: A Two-Stage Pumped-Storage Development in Switzerland." Water Power and Dam Construction, March 1976.

Guli, F.P. "European Pumped-Storage Plants." Symposium on Hydroelectric Pumped-Storage Schemes, August 1972.

Gunwaldsen, R.W. and Ferreira, A. "Northfield Mountain Pumped-Storage Project." Civil Engineering, May 1971, pp. 53-57.

Gynt, S. "Recent Development of Bearings and Lubrication Systems for Vertical Generators." ASEA Journal, 1947, p. 72.

Haase, C.D. "Castaic Pumped-Storage Project in California." Water Power, Vol. 23, pp. 333-341.

Habock, A., and Hofmann, H. "Static Frequency Converter for Starting Gas-Turbine and Pumped-Storage Sets." Siemens Review, XLI, No. 12, pp. 555-561.

Hagger, K., Hartmann, F. and Uitting, D. "Some Aspects of the Planning of Pumped-Storage Plants without Natural Inflows." World Power Conference, June 1960, Paper No. 11B/11, Madrid, Spain.

Hamlin, F.C. and Intrabartola, J.M. "Electrical Features of Smith Mountain Hydro Project." IEEE Transactions on Power, Apparatus and Systems, Vol. 88, No. 4, pp. 299-306.

Hamlin, J.B. "Experiences with Large Pump-Turbines at Niagara Falls." American Power Conference, 1964.

Hammons, T.J. and Loughran, J. "Starting Methods for Generator-Motor Units Employed in Pumped-Storage Stations."

Hanak, Z. "The Dalesice Pumped-Storage Scheme." Water Power and Dam Construction, May 1981.

Happoldt, H.K., Hartmann, O.J., and Wiedmann, E. "The Present State of Pumped-Storage in Europe."

Hartmann, O. and Meier, W. "Developments in High-Head Pumped-Storage." Water Power, March 1970.

Haswell, C.K. and Shaw, T.L. "Pumped-Storage - What is the Future?" Water Power, September 1974.

Haswell, C.K. et al. "Pumped-Storage and Tidal Power in Energy Systems." ASCE Proceedings, Vol. 98, PO2, No. 9297, pp. 201-220.

Haydock, J.L. "Energy Storage and Its Role in Electric Power Systems." 9th World Energy Conference.

Hearn, R.L. "The New Sir Adam Beck Generation Station at Niagara." IEEE Proceedings, Paper No. 2204 S, February 1957.

"Helms Pumped-Storage Project." PG&E, Report No. 10, October 1973.

"Helms Pumped-Storage Project." USCOLD Newsletter.

Henry, L.F. "Selection of Reversible Pump-Turbine Specific Speeds." International Pumped-Storage Conference, September 1971.

Henry, L.F. et al. "Mechanical and Hydraulic Considerations When Starting Reversible Pump-Turbines." International Symposium on Modern Electric Plants, October 1974.

Hight, H.W. "Cabin Creek Pumped-Storage Hydroelectric Project," ASCE Proceedings, Vol. 98, PO1, pp. 135-149.

"Hiwasee 102,000-HP Motor and Pump-Turbine." Power Engineering, Vol. 57, p. 59.

"Hiwasee Project Proposed Installation of Pump-Turbine Unit." TVA, Division of Water Central Planning, 1952.

Holden, O. "Three Pump-Turbines in Operation at Niagara." Electrical World, Vol. 149, No. 3, p. 56.

Housley, F.E., Peterson, G.E. and Corey, L. "Application of Hydrostatic Lubrication to Vertical Water Wheel Generator Thrust Bearings." AIEE Proceedings, Vol. 71, Part 111, p. 206.

"How General Electric Can Contribute Added Reliability to the Fairfield Pumped-Storage Hydro Plant." General Electric.

Hroncich, M.J. and Mullarkey, J.M. "Symposium on Pumped-Storage: Run-of-River Pumped-Storage - Smith Mountain Project." ASCE.

Hubbard, C.W. "Cabin Creek Pumped-Storage Project." Water Power, April 1968, pp. 129-134.

Hubbard, C.W. "These Factors must be Weighed in Developing Pumped-Storage Plants." Power Engineering, February 1966.

"Huge Pumped-Hydro Nears Completion." Electrical World, September 1, 1973.

"Hydrothermal Dispatch with Pumped-Storage." IEEE Transactions on Power, Apparatus and Systems, Vol. 85, pp. 472-485.

Iwanari, I. "The Okuyahagi Pumped-Storage Project." Water Power and Dam Construction, November 1975.

Jaeger, C. "Comments on Hydraulic Paper No. 10 by Professor H. Addison on 'Pumping Problems - Present and Future." Joint Meeting - Institute of Civil Engineers and Institute of Mechanical Engineers, May 1956.

Jaeger, C. "Pumped-Storage Capacity Correlated to Base Load Electrical Energy Generation: A Simplified Mathematical Approach." Institute of Civil Engineers, Vol. 14, pp. 291-318.

Jaeger, C. "Some Problems in Using Pumped Storage for Modern Power Development." Civil Engineering, April 3, 1960.

Jaeger, C. "The Future of Pumped-Storage." Electrical Review, December 25, 1959.

Jaeger, Dr. Chas. "The Correlation of Nuclear, Thermal and Pumped-Storage Capacity, Parts 1 and 3." Water Power, June and September 1958.

Jaeger, Dr. Chas. "The Economics of Pumped Storage - Parts I and II." Water Power, February and March 1957.

Jaski, F. "Application of Pump-Turbine." Allis-Chalmers Review.

Jaski, F. "New Reversible Pump-Turbine." Allis-Chalmers Review.

Jaski, F.E. "Field Testing a Reversible Pump-Turbine." ASME Paper No. 55-A-29.

Jaski, F.E. "One Machine - Two Functions . . . New Reversible Pump-Turbine." Allis-Chalmers Review.

Jaski, F.E. "Pump-Turbines - 1954 Progress Report." Allis-Chalmers Review.

Jaski, F.E. "Pump-Turbines Are Different." Power Engineering, May 1952.

Jaski, F.E. "The Pump-Turbine Story." Allis-Chalmers Review.

Jaski, F.E. and Thomas, W.E. "Intangibles Tip the Scale for Pump-Turbines." Electric Light and Power, April 1956.

Jaski, F.E. and Weltmer, W.W. "Reversible Pump-Turbines at Niagara Falls." ASCME, Paper No. 59-A-87.

Jaski, F.E. and Weltmer, W.W. "Reversible Pump-Turbines for Raccoon Mountain." Mechanical Engineering, March 1960, p.74.

Jaski, R. E. and Weltmer, W.W. "Reversible Pump-Turbine at Niagara Falls." Mechanical Engineering, Vol. 82, pp. 74-77.

"Jersey Utility Advances Pump-Storage Plan." Electrical World, August 1957, p. 73.

Johnson, G.D. "Pumped-Storage: An Evaluation of the Progress and Experience to Date with Large Reversible Units." World Power Conference, August 1968, Section C2, Paper No. 156, Moscow.

Johnson, G.D. "Worldwide Pumped-Storage Projects." Power Engineering, October 1968.

Johnson, P.J. et al. "Smith Mountain Pumped-Storage Project - Background, General Description and Const." American Power Conference, Vol. 28, pp. 678-688.

Johrde, P.S. "Generator-Motors for Pumped-Storage." Westinghouse Electric Corp., International Conference on Pumped-Storage Development and Its Environmental Effects.

Jonas, R.G. "Startup and Preliminary Operation - Taum Sauk Pumped-Storage Project." EEI, St. Louis, Missouri, September 1964.

Jonas, R.G. and Meagher, M.R. "Automatic Control for the Taum Sauk Project." AIEE District Conference, 1962, Paper DPA 62-758.

Jovarivic, B. "Present Situation and Future Trends in the Construction of Hydroelectric Pumped-Storage Schemes in Serbian Reg." Symposium on Hydroelectric Pumped-Storage Schemes, November 1972.

Justin, J.D. "Pumped-Storage Site Evaluation." Edison Electric Institute, April 1960.

Justin, J.D. "Rocky River Hydroelectric Development." ASCE Proceedings, Vol. 55, pp. 690-698.

Kaufmann, J.P. "The Dimensioning of Pump-Turbines." Water Power and Dam Construction, September 1977.

Kennedy, T. and Mabuce, E.M. "Dispatch of Pumped Hydro Storage on an Interconnected Hydrothermal System." IEEE Transaction on Power, Apparatus and Systems, pp. 446-457.

Kerkman, R.J., Lipo, T.A. and Newman, W.G. "An Inquiry Into Adjustable Speed Operation of a Pumped Hydro Plant - Part 2 - System Analysis." IEEE - General Electric, 1980.

Kimura, Y. and Yokoyama, T. "Planning of Reversible Francis Pump-Turbines." Hitachi, Ltd.

"Kinzua Dam's Powerhouse Moves in Three Directions." Engineering News-Record, August 8, 1968.

Kitand, Furukawa & Nagata. "Lateral Vibration of Generator-Motor and Pump-Turbine." Hitachi Review, Vol. 20, No. 7.

Knapp, S.R. "Pumped-Storage - The Handmaiden of Nuclear Power."

Koga, T. "Plant-Quality Index for Power-System Planning." Water Power, July 1966.

Kohlepp, C.E. and Thielmann, V.A. "Add Firm Hydro Capacity with Pumped-Storage." Electrical World, September 22, 1956.

Kroll, J. "Economic Pump Operation in Pump Storage Stations with Variable Heads." VDR Fachbrichte, 1931, pp. 60-63.

Kuchanowicz, A. "The Salina Hydro Project." Water Power, Vol. 20, pp.475-480.

Kusko, A. "Economics of Pumped in New England." International Conference on Pumped-Storage Development and Its Environmental Effects, 1971.

Kuwahara, S. "Equipping Pumped-Storage Stations in Japan." Water Power, March 1972.

Kuwahara, S. "Numappara Pumped-Storage Hydro Electric Project." International Conference on Pumped-Storage Development and Its Environmental Effects.

Kwiatkowski, R.W. and Perrce, L.D. "Environmental Design of Bear Swamp Project." ASCE Proceedings, Vol. 99, PO1, No. 9738, pp. 205-215.

"Large Scale Pumped-Storage - Parts I & II." Water Power, August and September 1959.

Lau, K.P. "Electrical Protection Features of the Jocasse Pumped-Storage Plant." IEEE/ASME Power Generation Conference, Paper C74 514-6.

Lawson, H.L. "Carters Pumped Storage Project Power Features and Pump Starting Method." International Conference on Pumped Storage Development and Its Environmental Effects.

Lee, W.S. "Keowee-Toxaway Project." American Power Conference, Vol. 29, pp. 707-8714.

Lee, W.S. "7,750 MW Project Meshes Nuclear, Hydro, Pumped Storage." Electrical World, October 16, 1967.

Lehman, C. et al. "Asynchronous Starting of Motor-Generators of Pumped-Storage Stations: Development of the Water Rotor." CIGRE Paper No. 11-01, 1972.

Lenssen, G. "General and Some Particular Cases of Grid Loads and Their Handling by Means of a Pumped-Storage Station." International Conference on Pumped-Storage Development and Its Environmental Effects.

Lenssen, G. "Some General and Special Trends in Pumped-Storage Development." Symposium on Hydroelectric Pumped-Storage Schemes, August 1972.

Ley, R.D. "Economic Analysis." Power Division Specialty Conference, August 1965, pp. 187-210.

Ley, R.D. "Pumped-Storage Session - Economic Analysis." ASCE.

Ley, R.D. and Liepe, W.E. "FPC Approves - Construction Begins on Yards Creek Pumped-Storage Plant." Electrical World, July 1963, pp. 92-94.

Ley, R.D. and Loane, E.S. "Symposium on Pumped Storage: General Planning of Pumped-Storage." ASCE Proceedings, July 1962.

Logan, T.H. and Christensen, R. "Interaction of Technical and Economic Factors in Pumped Storage Evaluation." U.S. Bureau of Reclamation, Denver, Colorado.

Lottes, Dr. Ing. Gerd. "The Development of European Pumped-Storage Plants." Water Power, January 1972.

Lowe, H.L. and Alton, R.J. "Electrical Features of Pumped-Storage Plants." EEI, May 1970.

"Ludington Pumped-Storage Facility - Largest of Its Type." Electric Light and Power, September 1973.

Lull, S.H. and Ferreira, A. "Northfield Mountain Pumped-Storage Project." ASCE Proceedings, Vol. 94, PO2, No. 6247, pp. 199-215.

Malamet, S. "Operation of Pumped-Storage Schemes." ASME, International Symposium on Waterhammer in Pumped-Storage Projects, 1965.

Marks, J.A. "Cabin Creek Extends Foruntires of Pumped-Storage Technology." Electric Light and Power, Vol. 46, pp. 75-78.

Mattern, D.H. "TVA Installing Largest Pump-Turbine at Hiwasee." Electrical World, July 5, 1954, p.16.

McCormack, W.J. "Performance Characteristics of Francis Type Pump-Turbines." ASME, Paper No. 55-S-45 Transactions, Vol. 78, No. 2, pp. 417-426.

McCreedy, C.T. "Challenges in Construction - Symposium." American Power Conference, 1974.

McDaniel, G.H. and Gabrielle, A.F. "Dispatching Pumped-Storage Hydro." IEEE Transactions on Power, Apparatus and Systems, Vol. 85, pp. 465-471.

Meacham, T.D. "Converting Salt River Reservoirs into Pumped-Storage Facilities." Engineering Foundation Conference, August 1975.

Meagher, R. "Combining Existing Surface Lake with Underground Reservoir for Pump-Storage." Engineering Foundation Conference, August 1974.

Meier, W. "Separate Hydraulic Machines or Reversible Pump-Turbines for Storage Plants."

Meier, W. et al. "Pump-Turbines and Storage Pumps." Escher Wyss News, 1972.

Meir, W. and Jaquet, M. "High Head Pumped Storage Plants." Modern Power Systems, Escher-Wyss, May 1981.

Meuer, H. and Mucke, J. "Trends in Power-House Construction for Pumped-Storage Stations."

Meyerand, R.G. "Engineering Behind the Automation Scheme at Taum Sauk Hydro Plant." Power Engineering (Two Parts), November and December 1962.

Meyers, J.F. and Armbruster, T.F. "Semi-Synchronous Starting." Allis-Chalmers Engineering Review, Vol. 33 No. 3.

Millette, A.J. "Bear Swamp Project-Energy-Environment-Ecology." Joint Power Conference, Boston, September 1972.

Missel, J.M. "Construction of Northfield Pumped-Storage Project." American Power Conference, April 1977.

Mittelstadt, R.L. "Potential for Pumped-Storage in the Columbia River Hydro System." Engineering Foundation Conference, August 1974.

Mock, C.H. "Electrical Features of Raccoon Mountain Pumped-Storage Plant." Tennessee Valley Authority, September 1971.

"Mock-Up of Niagara's Pump-Turbine." Engineering News-Record, July 31, 1958, p. 44.

Morgan, W.S. "Smith Mountain Pump Starting Methods." IEEE, Panel Discussion at Winter Meeting, January 1967.

Mosonyi, E. "Survey of Trends in Pumped-Storage Development." Symposium on Hydroelectric Pumped-Storage Schemes, August 1972.

Moyer, S. and Dickinson, W.H. "Muddy Run Pumped-Storage Project." American Power Conference, Vol. 29, pp. 699-706.

Muhlemann, E.H. "Arrangements of Hydraulic Machines for Pumped-Storage and Comparison of Cost, Efficiency and Starting Time." Escher Wyss News, 1972, pp. 3-11.

Muller, H. "A Survey of Pumped-Storage Potential in Switzerland." Water Power, May 1973.

"Multi-Stages Pump-Turbine Operation." Vevey Eng., November 1977.

Murray, W.T.L. et al. "Electrical Design Considerations for Reversible Pumped-Storage Hydroelectric Projects." CIGRE Paper No. 11-02, 1968.

Nassikas, J.N. "Development of Pumped-Storage Facilities in the U.S., 1972." Econ. Comm. for Europe, U.N. Econ. & Social Council, 1972.

"New Pump-Turbine Stimulates Interest in Pumped-Storage Development." Power Engineering, July 1950.

Newman, V.G. "The Use of Pumped-Storage in Electricity Supply." The EAMA Journal, May 1976, pp. 46-51.

"Niagara Project Data." New York Power Authority.

"Niagara Project: Big Job, Big Problems." Engineering News-Record, February 26, 1959, p. 30.

"Niagara Pumped-Storage Completes Fifth Year." Electrical World, August 13, 1962, pp. 68-69.

Nichols, D.E. and Yang, K.H. "Design Features of Bear Swamp Pumped Storage Project." ASCE, 1972.

Nielsen, E.G. and Cooper, E.A. "The Montezuma Pumped-Storage Project." IEEE, Region 6 Conference Paper, April 1969.

Noest, J.G. and Rich, G.R. "Cornwall Pumped-Storage Plant Will Do Multiple Duties on Consolidated Edison System." Power, July 1963, pp. 56-59.

Noyes, L.W. and Chvalier, R.G. "Operating Experience." American Power Conference, April 1979.

O'Donoghue, J.K. and O'Flaherty, R.M. "Design and Construction of the Cavern and Tunnels at Turlough Hill." Electricity Supply Board, Civil Works Department, Dublin.

Olken, M.I. and Petroro, N. Jr. "Smith Mountain Unit 3 - Control and Protection of a Pumped-Storage Unit."

"Operational Performance of High Head and High Speed Pump-Turbines." Water Power, November and December 1975.

"Operational and Availability Data for Blenheim-Gilboa." Power Authority of the State of New York, March 1977.

Panichelli, S. et al. "Pumped-Storage Plant Evaluation Planning Studies." Water Power and Dam Construction.

Paris L., Salvaderi, L. and Valtorta, M. "Energy Storage Peak Load Plants in the Future Energy Production Systems."

Paris, L. and Salvader, L. "Optimization of the Basic Characteristics of Pumped-Storage Plants." IEEE Presentation, Winter Meeting 1974, Paper C74, 158-2.

Paris, L. and Salvaderi, L. "Pumped-Storage Plants Basic Characteristics: Their Effect on Generating System Reliability." American Power Conference Proceedings, Vol. 36.

Parmakian, J. "Design Features of the Flatiron Power and Pumping Plant." Mechanical Engineering, Vol. 77, pp. 677-680.

Parmakian, J. "Design Features of the Flatiron Power and Pumping Plant." Water Power, Vol. 7, pp. 413-416.

Patrick, J.G. "The Cluster Layout - A New Concept for Pumped-Storage." Water Power, Vol. 24, pp.339-345.

Paul, K. Jr., et al. "Technical Features on Pump-Turbines for Helms Project - High Head Machines of New Generation."

Peneder, F. et al. "Static Equipment for starting Pumped-Storage Plant, Synchronous Condensers and Gas Turbine Sets." Brown Boveri, 1974.

Pennington, C.W. and Clark, J. "The Bath County Pumped-Storage Project."

Peterson, T. and Frank, K. "Starting of Large Synchronous Motors Using Static Frequency Converter." IEEE Proceedings, Vol. 91, pp. 172-179.

Peterson, T. "Starting Methods for Reversible Pumped-Storage Generator-Motors." ASEA Journal, 1973.

Pfafflin, G.E. "Future Trends in Hydro Pumped-Storage Equipment." American Power Conference, April 1974.

Pfafflin, G.E. "The Coo-Trois Ponts Pumped-Storage Hydro Station." Water Power, February 1970.

Pfafflin, G.E. "U.S. Trends in Pumped-Storage Technology." Allis-Chalmers, Power and Energy Systems Technical Sales Seminar, July 1973.

Pfafflin, G.E. "U.S. Trends in Pumped-Storage Technology." Allis-Chalmers Powertech 80, July 1980.

Pfisterer, E. and Kuhlmann, K.H. "Operating the Sackingen Ungerground Pumped-Storage Station." Water Power, November 1970.

"Potential Pumped-Storage Projects in the Pacific Southwest." Federal Power Commission, 1979.

Potocheney, G. "How to Protect and Synchronize Pumped-Storage Plants." Electric Light and Power, February 1967, pp. 63-65.

"Power from Pumped-Storage in Texas." Engineering News-Record, June 21, 1951, p. 37.

"Protective Relaying for Pumped-Storage Hydro Units." IEEE Presentation, Winter Meeting, Paper T 75-049-2.

"Prototype Head Test in Pumping Mode for 10,000-m Head Double Stage Pump-Turbine." Hitachi.

"Pumped Storage Plants are Solving the Peaking Problem." Power Engineering, January 1981, pp. 26-27.

"Pumped Storage for Hydroelectric Power - A Selected List of References in English." TVA Library.

"Pumped-Storage - An Answer to Increasing Power Demands." Engineering News-Record, April 4, 1958, p. 26.

"Pumped-Storage Builds Up a Head." Engineering News-Record, February 7, 1965.

"Pumped-Storage Can Be Unique." Electrical World, August 1, 1977.

"Pumped-Storage Comes to the Rescue (Of Manufacturers)." Electrical World, June 19, 1972.

"Pumped-Storage Hydro Plant Gives Small Stream Large Task." Engineering News-Record, Vol. 172, pp. 32-36.

"Pumped-Storage Hydroelectric Units Applied Under Low and High Heads." Power, July 1967, p. 117.

"Pumped-Storage Plants in North America." Power, Vol. 104, p. 154.

"Pumped-Storage Power, At Last, Comes Into Its Own." Engineering News-Record, January 2, 1969.

"Pumped-Storage Power." Mechanical Engineering, February 1960, p. 89.

"Pumped-Storage: State-of-the-Art Committee on Hydro Power Project Planning and Design." ASCE Proceedings, Vol. 97, PO3, pp. 675-695.

"Raccoon Mountain Pumped-Storage Plant (Summary of Principal Features)." TVA.

Reichwein, L. "Cabin Creek Pumped-Storage Hydroelectric Project - Operation and Maintenance," EEI, April 1968.

Revelle, J.E. and Mikitka, R.W. "Penstocks for Six Pumped-Storage Projects." ASCE Proceedings, Vol. 98, PO2, pp. 435-447.

"Reversible Pump-Turbine Unit", Mechanical Engineering, June 1956, p. 541.

Reynolds, J. Z. "Water Quality in Pumped-Storage Reservoirs." ASCE Journal of the Power Division, October 1967.

Rheigans, W.J. "Case for Hydro Peaking." Electrical World, December 1960.

Rheigans, W.J. "Operating and Maintenance Experience with Pump-Turbines in Brazil." ASME, December 1965.

Rheigans, W.J. "Operating and Maintenance Experience with Pump-Turbines in the U.S., Italy and Japan." ASME, December 1965.

Rheingans, W.F., Jaski F. and Roth. H.H. "Pumped-Storage." Midwest Power Conference, Vol. 13, pp. 153-162.

Rheingans, W.J. "Hydro and Pumped-Storage Economic in Low Load Factor Duty." Allis-Chalmers, Special Report on Sources of Peaking Power, December 1960.

Rich, G.R. "Pumped-Storage Economics." American Power Conference Proceedings, Vol. XX, p. 390.

Robertson, L.M. "The Design and Construction of Cabin Creek Pumped-Storage Hydroelectric Project." ASME/IEEE Joint Power Generation Conference, Paper 31, pp. 66-547.

Robertson, L.M. et al. "Electrical Design and Testing of Cabin Creek Pumped-Storage Hydroelectric Project." IEEE Transactions on Power, Apparatus and Systems, Vol. 87, No. 3, pp. 844-854.

Robertson, L.M. et al. "High Altitude Pumped-Storage Plant to Develop 325 MW at 1,190 Foot Head." Electrical World, July 1965.

Robertson, L.M., et al. "The Cabin Creek Pumped-Storage Hydro-Electric Project - Performance and Testing." IEEE and ASME Joint Meeting, January 1968, Denver, Colorado.

Roche, N., et al. "Tests on a French Adjustable Two-Stage Pump-Turbine." Water Power and Dam Construction, June 1985.

Rock, S.B. "Seneca Plant: Unconventional Approach Provides Unusual Operating Flexibility." Electric Light and Power, December 1967, Vol. 45.

Rogers, F.C. and Allen, A.E. "Energy Storage Underground." Harza Engineering Company, Chicago, Illinois.

Roth, H.H. "Electrical Requirements of Reversible Pumped-Storage Units." AIEE Transactions, Vol. 75, No. 10, pp. 1129-1133.

Roth, H.H. "Generator-Motor Units for Reversible Pump-Turbines." Allis-Chalmers.

Roth, H.H. "Generator-Motors for Storing Energy." Allis-Chalmers Press, 1963.

Roth, H.H. "Hydrogenerator Thrust Bearings." Allis-Chalmers Engineering Review.

Roth, H.H. "Recent Developments in Hydro-Generators." Allis-Chalmers Press.

Roth, H.H. "Starting Requirements of Reversible Pumped-Storage Units."

Roth, H.H. "Unit Must Fit System Conditions." Electrical World, May 12, 1958.

Roth, H.H. and Armbrurster, T.F. "Starting Large Synchronous Machines." Allis-Chalmers, Manuscript for Presentation ASME/IEEE Joint Power Conference, August 1966, Denver, Colorado.

Roth, H.H. and Armbruster, T.F. "Starting Large Pumping Units." Paper No. 10-R-2704-5.

Rouve, G. and Nelihsen, W. "Planning Criteria for Civil Engineering and Mechanical Components of Hydro Pumped-Storage Power Plants." Technical University, West Germany.

Rowntree, S. "Pumped-Storage and Waterwheel Generators." Electric Utility Engineering Conference, March 1971, Subject 24.

Rudolph, E.A. "Planning and Design of Taum Sauk Pumped-Storage Hydroelectric Project." ASCE, Phoenix, Arizona, April 1961.

Rudulph, E.A. "Hydraulic and Structural Features of Taum Sauk Project." Presented to EEI in St. Louis, Missouri, 1961.

Rudulph, E.A. "Taum Sauk Pumped-Storage Power Project." Civil Engineering, January 1963, p. 40-43.

Ruud, F.O. "Pumped-Storage Potential at Existing Hydroelectric Sites of the Bureau of Reclamation." Engineering Foundation Conference, August 1974.

Saloma, J. "Niagara Hydro Power Project to Cost New York $705 Million." Electrical World, January 19, 1959, p. 34.

Salzman, M.G. "Symposium on Pumped Storage: Site Investigations of Pumped-Storage Facilities." ASCE Proceedings, July 1962.

Samolis, R.P. "Electrical Features of the Northfield Pumped-Storage Project." IEEE Transactions on Power, Apparatus and Systems, Vol. 88, No. 8, pp. 1291-1297.

Samolis, R.P. "What's The Best Pump Start Mode for Big Pumps - Hydro?" Electric Light and Power, November 1970, pp. 35-37.

Sanematsu, T. and Fujimoto, S. "326 MVA/350 MW Generator-Motors for Nabara Power Station." Hitachi Review.

"San Luis Pumped-Storage Unit to be Among Nation's Largest." Power Engineering, Vol. 68, pp.42-44

Scherer, C.R. "Load Management Economics with Pumped-Storage." ASCE, Journal of the Energy Division.

Schmitt, G.E. "Pumped-Storage Hydro Plant in Texas Proves Economical." Civil Engineering, May 1951, p. 21.

Schnick, A.M. and Watchorn, C.W. "Computer Program for Determining the Economic Size of Development of Pump-Storage Hydro Sites." IEEE Transactions on Power, Apparatus and Systems, Vol. 85, pp. 1154-1163.

Seguin, R.L. "Startup and Operating Experience." American Power Conference, 1974.

Seibert, C.J. "Pumped-Storage." Engineering News-Record, April 10, 1948, p. 110.

Sellars, L.R. and Kirkland, Jr. J.R. "Pump-Turbine Unit 2 Addition at TVA Hiwasee Hydro Plant." AIEE Transactions, 75, Part 3, p. 849.

Sellers, L.R. and Kirkland, R.E., Jr. "Pump-Turbine Addition at TVA Hiwasee Hydro Plant." AIEE, Paper No. 56-145 and Electrical Engineering, Vol. 75, pp. 263-269.

Sequin, R.L. "Ludington Pumped-Storage Hydroelectric Generation Station - Start-Up and Operating Experience." American Power Conference, May 1974.

Sequin, R.L. and Gerkowski, R.F. "Ludington Pumped-Storage Hydroelectric Generating Station - General Plant Construction and Electrical Details." IEE, May 1973.

Shaw, T.L. and Thorpe, G.R. "Integration of Pumped-Storage with Tidal Power." ASCE Proceedings, Vol. 98, P01, pp. 159-180.

Shortley, P.B. and Skooglund, J.W. "System Planning with Pumped-Storage - Two Programs Facilitate the Economic Analysis." IEEE Conference, Paper 71 CP95-PWR.

Shoyama, E. "Synchronous Starting of Generator-Motor Units at Pumped-Storage Power Stations." Hitachi Review, Vol. 17, No. 1, pp. 2-7.

Siebensohn, R.B. "The Jocasee Project - A Hydro and Nuclear Power Partnership." Water Power, Vol. 22 pp.237-240.

Siebensohn, R.B. "Trends in U.S. Hydro Equipment Design." Water Power, Vol. 26, pp. 44-50.

"Single Pumping and Generating Unit Built for Pumped Storage Hydro Plants." Engineering News-Record, October 6, 1948, p.110.

Sloane, E.S. "Planning for Pumped-Storage." American Power Conference, Proceedings, Vol. XX, p. 403.

Sloane, E.S. "Planning for Pumped-Storage." Pennsylvania Electric Assoc., System Planning Committee, May 1957.

Sloane, E.S. "Pumped-Storage Hydro Attractive." Electrical World, September 23, 1957, p. 73.

Small, W.D. "Electrical Features of the Sir Adam Beck-Niagara Pumped-Generating Station." AIEE Transactions, Vol. 77, Part 3, pp. 950-955.

"Solid-State Device Protects Pumped-Hydro." Electrical World, February 16, 1970, p. 37.

Solomon, F.P. and Cooper, E.A. "Seneca Pumped-Storage - Four Years Operating Experience." Electrical Association Meeting, Canada, March 1974.

Sond, M., et al. "The Results of Field Test on 310 MW Francis Pump-Turbine." Technical Review, October 1976.

"Special Pumped-Storage Features." Water Power, Vol. 22.

Spink, C. "Pumped-Storage Hydroelectric Power." Power Engineering, October 1951.

Spink, C.S. "How Pumped-Storage Can Pay Off For You Today." Power Engineering, October 1951.

Stelzer, R.S. and Walters, R.N. "Estimating Reversible Pump-Turbine Characteristics." U.S. Department of the Interior, Bureau of Reclamation, December 1977.

Stout, J.J. and Thomas, M.F. "Major Pumped-Storage Projects in the U.S." ASCE, May 1968.

Stroh, R.G. et al. "Rapid Reversal of San Luis Pumped-Generating Units." IEEE Transactions on Power, Apparatus and Systems, Vol. 89, No. 6, pp. 1106-1111.

Strub, R.A. "Pressure Fluctuations and Fatigue Stresses in Storage Pumps and Pump-Turbines." ASME, Paper No. 63-AHGT-11.

Sullivan, R.K., Jr. "Sizing of Pumped-Storage Conduits." ASCE Proceedings, Vol. 97, No. 3, pp. 667-673.

"Survey of Pumped-Storage Projects in the U.S. and Canada to 1975." IEEE Report, January 1976.

"Survey of the World's Pumped-Storage Station." Water Power, March 1970.

Swed, R.J. and Yang, K.H. "Experience on Startup and Trial Operation at Yards Creek Pumped-Storage Project." ASME Transactions, Paper No. 68-WA/FE-14, Vol. 91D, pp. 387-396.

Swift, W.L. "Optimizing Turbine and Pumped-Turbine Design by Use of Computers." Water Power, September 1971, pp. 325-332.

Takaoe, Okada, Tateishi, etc. "Recent Large Capacity Pump-Turbines and Generator-Motors." Hitachi Review, Vol. 20, No. 7.

"TVA Installs Largest Pump-Turbine." Engineering News-Record, June 21, 1956.

Terry, R.V. and Jaski, F.E. "Test Characteristics of a Combined Pump-Turbine Model." ASME Transactions, Vol. 64 No. 8.

"The Seneca Pumped-Storage Plant." American Power Conference Proceedings, Vol. 29, pp. 720-730.

"The World's Pumped-Storage Plants (List)." Water Power and Dam Construction.

Thompson, Jr., Major H. "Wallace Dam." ASCE Proceedings, October 1972.

Thon, General Aspects of Pumped-Storage Hydro Power." Water Power, March 1970.

Thorgerson, T.E. "Electrical Features of the Niagara Power Project." AIEE Summer Meeting, June 1961, Conference Paper CP 61-868, New York.

Thorgerson, T.E. and Basilesco, J. "Electrical Controls and Protective Relaying - Niagara Power Project." AIEE Summer Meeting, Conference Paper CP-61-869, New York.

Thorgerson, T.E. and Basilesco, J. "Electrical Features of Niagara Power Project." Electrical Engineering, Vol. 80, pp. 739-744.

Thorpe, G.R. and Shaw, T.L. "The Case for Low-Head Estuarial Pumped-Storage." Water Power, Vol. 22 pp. 107-108.

Tondevold, E. "Pumped-Storage in Norway." International Conference on Pumped-Storage Development and Its Environmental Effects.

Towne, R.A. "Trends in Hydro Generator Design and Application to Pumped-Storage." Westinghouse Electric Corp.

Troost, T.W. "Electrical Machinery and Apparatus for the Hyatt-Thermalito Pumped-Storage Power Plants." Department of Water Resources, State of California. International Conference on Pumped Storage Development and Its Environmental Effects.

"Union Electric Co. Adds 350,000 Kilowatts, Taum Sauk." Engineering News-Record, August 1963.

"Union Electric Plan $50 Million Project to Store Electricity." Wall Street Journal, December 1959.

"Union Electric Studies Pump Storage." Electrical World, Vol. 146, p. 8.

Van Vranken, W.P. "Black Start for Pumped-Storage Units." Allis-Chalmers Engineering Review, Vol. 38, No. 3, pp. 11-13.

Van Vranken, W.P. "Costs Go Down With Solid State Excitation." Electric Light and Power, July 1966.

Vanscant, C. "High Tech Hydro: An Overview of Pumped-Storage." Hydro Review, Summer 1985.

Vasilescu, M.S. "Some Design Criteria for Underground Pumped-Storage Plant Surge Tanks."

Vasilescu, M.S. "The Design Implications of Some Rock Mechanics Problems Peculiar to Pumped-Storage Plants." ASCE, January 1970.

Vasilescu, M.S. et al. "Design and Construction - Blenheim-Gilboa Pumped-Storage Project." American Power Conference, April 1976.

Velz, C.J. "Environmental Impacts, Detrimental and Beneficial of Pumped-Storage Dual Power/Water Systems." Symposium of Hydroelectric Pumped-Storage Schemes, 1972.

Vencill, G.J. "Application of Pumped-Storage Hydro to Midwestern Terrain." American Power Conference Proceedings, Vol. XX, p. 414.

Vencill, G.J. "Factors Governing Selection of Large Pumped-Storage Project to Serve Utility Peak Loads." 6th World Power Conference, Australia, 1974.

Vencill, G.J. "Operating Experience at Taum Sauk." ASCE.

Vencill, G.J. "Operating Experience at Taum Sauk Pinpoints Problem Areas." Electric Light and Power, Vol. 44, pp. 30-39.

Vencill, G.J. "Operating Experience with Taum Sauk." IEEE Meeting, Conference Paper CP-64-36, Tulsa, Oklahoma, August 1974.

Vencill, G.J. "The Taum Sauk Development - Part 1." Electric Light and Power, April 1961, pp. 46-49.

Wachter, G.F. "Pumped-Storage at Oroville - Design and Initial Operation." IEEE Transactions on Power, Apparatus and Systems, Vol. 90, pp. 1217-1224.

Walker, J.H. "Generator-Motor Problems in Pumped-Storage Installations." The Institution of Electrical Engineering, December 1958.

Walker, R.F. and Hugo. R.V. "Pumped Hydro Peaking Displaces Steam Units." Electrical World, July 25, 1965, pp. 52-53.

Waltman, R.H. and Howell, R.E. "Jocassee Pumped-Storage Project - Startup, Testing and Operation Experience." IEEE Proceedings, Winter Meeting, 1975, Paper T75 201-9.

Warnock, J.G. "Milestones in Pumped-Storage Development." Engineering Foundation Conference, August 1974.

Warnock, J.G. "Trends Established 20 Years of Modern Pumped-Storage Practice and for the Future." International Conference on Pumped-Storage Development and Its Environmental Effects, 1971.

Warnock, J.G. and Smith, B.L. "Trends in Pumped Storage and Compressed Air Energy Storage Development."

Warnock, J.G., and Smith, B.L. "Trends in Pumped-Storage Development." Water Power and Dam Construction, August 1984.

Watchorn, C.W. "General Basis for Planning Characteristics of Pumped-Storage Hydro Capacity." IEEE Transactions on Power, Apparatus and Systems, Vol. 84, pp. 464-481.

Watchorn, C.W. "Some General Basic Planning Characteristics of Pump-Storage Hydro Capacity." Pennsylvania Power and Light Co.

"Water Hammer In Pumped-Storage Projects." Water Power, March 1966.

Wenders, J.T. "Peak Load Pricing in the Electric Utility Industry." The Bell Journal of Economics.

Whitehead, C.F. and Famner, W.J. "Initial Planning, Design Considerations and Model Studies - Symposium." American Power Conference, 1974.

Whitlow, G.S. "Taum Sauk Development." Electric Light and Power, April and May 1961.

Whitney, E.C. "Assembly, Shipping, kVA Limits Challenge Pumped-Storage Designers." Electric Utility Engineering Conference (Generator-Motors), Subject No. 13, 1968.

Whitney, E.C. "Pumped-Storage for Peaking and Emergency Service (Generator-Motor Considerations)." Electric Utility Engineering Conference, April 1967.

Wilson, F.M. "Pumping for Power in the Colorado Rockies." AIEE Transactions, Vol. 67, Part 3, p. 1127.

Wirschal, H.H. "Reversible Pump Turbines for Raccoon Mountain." International Pump Storage Conference, September 1971.

Wolf, N.N. "Pumped-Storage Hydro costs Per kW Are Competitive." Electrical World, May 8, 1948.

Wolff, N.N. "Economic Possibilities of Pumped-Storage Hydro-Electric Plants." Engineering News-Record, April 29, 1948, pp. 85-87.

Woodruff, R.S. "Pumped-Storage: State of the Art (Panel Discussion)." ASCE Proceedings, Vol. 97, PO3, pp. 667-673.

Woodward, T.R. "Operating Experience with Pumped-Storage Hydro on a Power Pool Basis (PJM Interconnection)." Engineering Foundation Conference, August 1974.

"Work Moving on Lakeside Pump-Storage Project." Electrical World, August 18, 1968, p.23.

"World's Largest Reversible Pump-Turbine." Water Power, June 1956, p. 237.

Yamabe, M. and Yamaguchi, Y. "Index Method for Pumping Operation of Reversible Pump-Turbine." Paper No. 68-WA/FE-5.

Yamabe. "Hystersis Characteristics of Francis Pump-Turbines When Operated as Turbines."

Yamaguchi and Tanaka, etc. "Calculation of Transient Phenomena in Turbines and Pumps." Hitachi Review, No. 13.

Yamamoto, K. et al. "Present Trends of High-Head Reversible Pump-Turbines." Hitachi, Ltd.

Yamamoto, N. "Operational Performance on Reversible Pump-Turbines." IAHR, September 1966.

Yang, K.H. and Nichols, D.E. "Bear Swamp Pumped-Storage Plant Will Start Up This Summer." Water Power, Vol. 26, pp. 157-163.

Yoshida, M. "The Okuyoshino Pumped-Storage Station." Water Power and Dam Construction, October 1979.

Yoshimoto, T. "The Atashika Sea-Water Pumped-Storage Project." Water Power, February 1972.

Zagars, A. "Bath County Pumped Storage Project Underground Features." ISRM.

Zagars, A. and Hasgood, J.M. "Bath County, A 2100 MW Development in the USA." Water Power and Dam Construction, October 1977.

Zagars, A. and Kleiner. "Bath County Hydroelectric Pumped-Storage Project." Harza Engineering Company.

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